The Cedar River Sockeye Salmon Hatchery Plan

Introduction:

The Cedar River Sockeye Salmon Hatchery Plan specifies recommendations on hatchery design and operation with considerations given to potential genetic, health, and ecological risks associated with artificial propagation of sockeye in the Cedar River and Lake Washington system. The plan is the product of the special scientific advisory panel formed as part of the process agreed upon by the City of Seattle with other signatory parties of the Landsburg Mitigation Agreement to implement an effective, comprehensive, and biologically sound artificial propagation program consistent with the Habitat Conservation Plan for the Cedar River. The plan includes assessments that should be undertaken to study the long-term effects of the hatchery on the Lake Washington system and to provide information pertinent to adaptive management of the facility.

Under the mandate of the Landsburg Mitigation Agreement, the mission assumed by the panel was to provide recommendations specifically for the design and operation of a sockeye salmon hatchery. The feasibility of other enhancement measures that would also be capable of producing wild or wild-like juvenile sockeye such as spawning channels, side channel incubation, and habitat restoration as alternatives to the more traditional hatchery, therefore, were not considered by the panel. Consequently, the substance of this document is a series of recommendations that the panel believes will make the hatchery as effective and biologically sound as possible.

In this report, the advisory committee notes that there is a great scope for improvement in hatchery management in the Pacific Northwest. Concerns over traditional hatchery practices by agencies and management groups have shifted the management of hatchery programs more towards a conservation ethic. Such a theme has become evident in many new plans formulated to reform the Pacific Northwest hatchery system. Although no traditional sockeye hatchery presently exists that applies conservation strategies for production, scientific information now available makes it feasible and practical to artificially propagate juveniles similar in development, growth, and behavior to their wild cohorts. A conservation hatchery in the context of the Cedar River project may be defined as a facility to breed and propagate sockeye salmon with genetic, behavioral, morphological, and physiological characteristics equivalent to that of the wild counterpart. The committee believes that implementation of the plan adopting a conservation hatchery philosophy, will conserve bio-diversity and the role of sockeye compatible with the integrity and health of Lake Washington ecosystem.

With specific regard to artificial propagation, the plan calls for the use of culture technologies that minimize adverse ecological interactions between hatchery and wild fish, and strategies that conserve existing gene pools. The basic premise for a conservation hatchery is that if the hatchery produces fish that demonstrate the behavior and life history pattern of wild fish, then survival will be improved and negative interactions between hatchery and wild fish will be reduced. Consequently, recommended strategies for artificial propagation are designed to match the particular requirements and diversity of the sockeye population units within the Cedar River system. The Cedar River sockeye hatchery will operate under the concept that high quality sockeye juveniles, behaviorally and physiologically similar to their wild cohorts, can be produced under conditions which simulate the natural life history of their wild cohorts.

And finally, this committee agrees with other published accounts (Waples 1999, Mahnken et al. 1998, Rhodes and Quinn 1998, Steward and Bjornn 1990, Flagg et al. 1995, Brannon 1992), that hatcheries are intrinsically neither good nor bad, but their value is determined only in the context of their goals and operational strategies. Therefore, a major effort of the panel has been to clearly elicit the goals of a conservation-style hatchery that strives to maintain bio-diversity, is adaptively managed through science-based monitoring and evaluation, and is supported by a strong research program. It is also imperative to understand that achieving the success desired in the sockeye enhancement program also requires that the habitat for natural spawning, incubation, and migration to the lake represents a healthy environment. This emphasizes that the conservation hatchery program is not dependent just on the constructed facilities, but rather on the entire ecosystem that hatchery production helps seed and in which the returning spawners can successfully reproduce naturally.

Section I. Background:

Oncorhynchus nerka is represented by the anadromous form, sockeye salmon, and the freshwater resident form referred to as kokanee. Both forms are believed capable of producing the other (Brannon 2000, Foerster 1947) and show similar migratory behavior (Danner 1994), and on occasion have been observed to spawn interspecifically (McCart 1967). When the two forms co-exist, and where access to freshwater production areas is not restricted, the anadromous form tends to strongly dominate over the resident form. Kokanee generally occur in high abundance only when sockeye are absent or limited in their nursery environment in some manner. Geographic distribution of the resident form overlaps that of the anadromous form except in the northern latitudes where kokanee are absent. Both forms reside in the Lake Washington system.

Lake Washington represents a unique sockeye system and one that is expected to continue in a pattern of change as sockeye abundance increases. Although there is evidence that sockeye existed historically in the system, the present Cedar River population, and perhaps other segments of the population inhabiting the system, are relatively new. With the 1916 diversion of the Lake Washington outlet from the Black River and through the Lake Union cut, significant changes occurred in the ecosystem (Woodey 1966). By the mid-1930s anadromous sockeye were considered extinct in the basin. Efforts were undertaken to rehabilitate Lake Washington as a sockeye system through introductions from 1937 through 1963. The critical importance of the nursery

environment, however, was underscored by the fact that while nearly 5 million juvenile sockeye were released in the system over a twenty seven-year period, success wasn't observed until the 1960s. Prior to that time Lake Washington had undergone severe eutrophication as the disposal destination of a major sewage system in the watershed. When METRO diverted waste from entering the lake in the mid-1960s, water quality showed rapid improvement, and concurrently sockeye responded with major changes in population strength over subsequent years.

The Cedar River, flowing into the south end of the lake, serves as the primary sockeye incubation system in the basin. As a fall spawning species, the fall and winter temperatures in the river represent a suitable range for spawning and incubation of sockeye. However, daily maximum temperatures during the summer generally exceed 14˚C from June to mid-August (Figure 1). Temperatures above that point approach the lethal level for developing embryos, but acceleration in development rate at those temperatures would also result in lake entry of fry too early in the year for meaningful survival. Consequently, while adult fish are observed in the river during summer months, the main spawning period doesn't begin until maximum temperatures drop below 13˚C in September. Spawning then continues into January over a temperature range dropping to around 3˚C, making the Cedar River one of the warmest overall incubation stream environments exploited by natural sockeye populations.

Figure 1. Generalized annual temperatures for the Cedar River.

Consistent with the rate of development for sockeye embryos, and given the temperature regime of Cedar River, eggs spawned at the beginning of September will experience something around a mean of 8˚C over an incubation period of about 130 days, and emerge around the end of December. In contrast, eggs spawned during the first week of November will experience a mean temperature around 4˚C over a period of approximately 200 days, emerging sometime in mid-May. Prolongation of the incubation periods by as much as 14 days would occur at oxygen levels substantially below saturation, but emerging fry would still have more than sufficient time to reach large age-1 smolt size because Lake Washington offers a very favorable rearing environment.

Fry entering the lake from the fall and winter spawners experience rearing temperatures and a food supply that exceeds most other sockeye nursery systems. Growth rate of sockeye in Lake Washington results in a mean smolt weight at age-1 well over 12 grams, nearly double that of sockeye in most lakes immediately north in the Fraser River. Early emerging fry enter the lake with surface temperatures around 6 ˚C, while fry entering in May can experience temperatures well above 12˚C, and thus demonstrate markedly different growth rates. Lake Washington sockeye fingerling growth has been shown to continue through winter months, which is unique compared to most sockeye systems (Figure 2). Also good spring growing conditions can give Lake Washington sockeye a further size advantage that benefits subsequent size-related marine survival.

Figure 2. Lake Washington sockeye juvenile growth trajectory in weight gain.

Several other unique population characteristics have been demonstrated in Lake Washington sockeye. In addition to the largest smolts recorded anywhere in the geographic range of the species, they are represented by three age classes of migrants (age-0, age-1, age-2 smolts) and the resident form that remains in the system. Adults return to spawn in Cedar River over a seven month period, and fry emergence ranges over eight or nine months of the year, with both patterns atypical to the extreme.

In reviewing the environmental factors most important in the elaboration of sockeye life history, temperature and the nutrient base are the most critical elements. The timing patterns that temperatures evoke define the options available to sockeye populations (Brannon 1987), and the nutrient base available as feed determines which of those options are exploited in development of life history strategies. The near optimum temperature regime and the nutrient base in Lake Washington have permitted the broad diversity in sockeye timing because sufficient growth can still be attained to achieve migratory success over the expanded period of lake-entry. Adult spawning time, which is determined by feed-back from the survival success of the resulting fry within the respective spawning segments of a run, hasn't been under the strong selective pressures in Lake Washington that normally constrain expansion of the peripheral elements of populations in most other systems. Consequently, favorable growing conditions have worked to sustain the broader spawning and emergence patterns that now characterize Cedar River sockeye, and have become established as genetic differences that contribute to the diversity of the population.

The temporal diversity in the system also suggests that the Lake Washington sockeye ecosystem could continue to evolve until the population biomass reaches equilibrium with nutrient resources in the lake. Under the favorable growth regime in the lake, the broad spawning and emergence timing patterns have occurred because the biomass of the sockeye in the present system thus far has never seriously challenged the rearing capacity. One reason suggested for the situation is that high flows have diminished incubation survival frequently enough to have minimized selective intraspecific competition within the Cedar River population. If the extremes in the Cedar River hydrograph have compromised incubation success of the main body of incubating fry frequently enough, it would have reduced selective exclusion of the fringe elements in the population under the highly productive lake environment. As the population size increases through increased return and incubation survival success, the system may tend towards equilibrium which could be demonstrated by reaching a plateau in smolt abundance, and a more consolidated peak in spawning and fry emergence.

Another outcome accompanying the increase in the size of the sockeye population was the concurrent reduction in the estimated abundance of kokanee residing in the basin (Connor and Kvam 2000). However, as mentioned above, in the face of continuing large returns of sockeye to any lake system, suppression of the resident form of *O. nerka* over time is anticipated through the competitive advantage that sockeye have as an anadromous and larger form of the species. In Lake Washington, therefore, as sockeye became well established in the system, the reduction of kokanee occurred as should have been expected, with numbers dropping off and sustained at a much lower level than what existed previously in the absence of sockeye. Continued low representation, or even a further reduction in kokanee abundance is anticipated in response to the sockeye enhancement program.

An important element ancillary to the mitigation objectives of the hatchery on the Cedar River is improvement of the inter-annual stability of the sockeye population. Since the expansion of the run in the late 1960s, sockeye production in Lake Washington has shown marked fluctuations in abundance, so severe that harvest has been curtailed for periods of several years. The cause of these periodic crashes has been attributed to various factors, but the situation has major implications on how the hatchery program should be viewed with regard to mitigation and enhancement processes, and is given special attention in this report. A review of the irregularity in return success, sources of mortality, and potential bottlenecks in food supply confronting each life stage of the sockeye is helpful in understanding these patterns, with descriptions how these challenges vary among the habitats occupied during the incubation, migration, and freshwater rearing phases.

Irregularity in Patterns of Sockeye Abundance:

The pattern of the Lake Washington sockeye population increase and irregularity in return abundance (Figure 3) has been a troubling element in the consideration of population health. Some causes of variability will be addressed directly by the hatchery program, but others are from root effects of environmental conditions for which the hatchery will have no influence except to increase the population base. The point is, however, that any of the factors affecting variability in return can have an influence on population structure of the Lake Washington sockeye and the length of time required to reach its production potential. The several factors that influence survival are presented below.

Figure 3. Estimated annual abundance of Lake Washington sockeye salmon return run

(Data from Washington Department of Fish and Wildlife).

Marine conditions and return variability - Lake Washington sockeye return to freshwater early in the year. A major portion of the population enters the Strait of Juan de Fuca and Puget Sound at the same time as the Early Stuart run returning to upper Fraser River and mixes with the Early Stuart fish at least during the terminal part of their marine migration. Success of the early component of Fraser sockeye has been equivocal, with substantial variability associated with unfavorable migration conditions in flow and temperature, but also subject to uncertain marine conditions associated with spring migration that potentially can affect all early returning sockeye populations. Returning early, but holding for a period of time in Lake Washington while being sustained by their stored energy reserves, also creates a level of risk that is difficult to evaluate without ready access to the fish. However, by the near failures of the early returning Fraser sockeye stocks, early return timing of the Lake Washington population may experience the same survival variability that is observed in other early returning populations. Even with good freshwater survival, Lake Washington sockeye could experience poor return success due to marine conditions associated with their early return pattern.

Fish health considerations. - Like other salmonids, sockeye are susceptible to a variety of infectious diseases. While several of these are known to affect fish in the wild, they may become especially problematic when sockeye experience extended periods of time in a hatchery. Among the most important diseases affecting sockeye salmon are infectious hematopoietic necrosis, bacterial kidney disease, bacterial gill disease, bacterial coldwater disease, furunculosis, whirling disease, and diseases caused by a variety of external and internal parasites and fungi. Some of these diseases are not known to be present in the Cedar River watershed (e.g. whirling disease), but could become of major concern if introduced. For sockeye eggs and fry in hatcheries, infectious hematopoietic necrosis (IHN) can be especially devastating, and special measures must be in place to avoid infection of fry with the causative virus (IHNV). In the Cedar River, IHNV is very prevalent in the wild sockeye population where it is maintained in an annual cycle infecting both returning adults and emergent fry in the system. The virus is transmitted among fish through waterborne exposure (horizontal transmission) and from infected adults to their fry via contamination of the eggs at spawning (vertical transmission). There has been the demonstrated waterborne transmission of IHNV to rainbow trout held in live boxes in the Cedar River (Crewson 1992), which suggests the possibility of horizontal transmission of IHNV from late spawning adults to early emerging fry in the Cedar River. The prevalence of IHNV infection is nearly 100% among late spawning Cedar River sockeye. Leeches in the Cedar River are also known to harbor IHNV and may be an important vector for transmission of the virus between fish (Mulcahy et al. 1990), but their role as an alternate host or reservoir for IHNV has not been conclusively determined. In addition to its potential effects on fry reared in the Cedar River sockeye salmon hatchery, most certainly, IHNV affects the survival of naturally reared fry and successfully returning adults in the Cedar River sockeye salmon population. Either wild or hatchery-produced fish carrying IHNV that experience stress from adverse environmental factors or that are present in crowed conditions, could be a serious problem in spreading the disease and in causing substantial mortality among fry or pre-spawning adults. An important feature of the Cedar River Hatchery Plan will be to

monitor the presence and levels of infectious diseases in the Lake Washington system. Efforts spent in these assessments will work together in reducing the effects of IHNV and other infectious diseases on all segments of the sockeye salmon population.

Eggs, alevins, and fry in the Cedar River - The factor alleged to have the greatest influence on overall performance of the population has been associated with reduced incubation success from problematic stream flows, specifically floods and loss of redd sites, and possible effects of IHNV infection during incubation and early lake residence. The original enhancement plans developed in the 1970s was developed around the premise that incubation losses were the primary cause of poor adult returns. Eggs and alevins incubate in gravel redds in the stream bed during the fall and winter where they are susceptible to effects from overspawning, scouring during autumn and winter floods, redd dewatering, and predation by sculpins or other fishes. Egg mortality is strongly correlated ($r^2 = 0.90$) with the severity of flooding during the incubation period Seiler and Kishimoto 1997). Fry emergence begins in late December or January, reaches relatively high, sustained levels during February through April, then declines through May. Fry emerge from the gravel at night and migrate immediately to the lake the same night. Predation on migrant fry in the river has been documented for wild steelhead smolts (Beauchamp 1995), coho smolts, cutthroat and rainbow trout (Beauchamp 1995, Tabor and Chan 1996, Tabor et al. 1998), and sculpin $\geq$ 50 mm total length (Tabor et al. 1998). Survival by migrant fry in the stream is also strongly and positively correlated ($r^2 > 0.80$) with higher flows in the Cedar River (Seiler and Kishimoto 1997), suggesting that faster passage rates and higher turbidity associated with higher flows help fry avoid predators as they migrate to the lake.

Regardless of where mortality may occur during this life phase, increased production of virus-free fry through the hatchery program should have a positive influence on the number of returning adults. Increasing the production base and providing a measure of stability through the hatchery program will assist in the long-term success of sockeye in the system by eliminating the intensity of incubation losses from floods and INHV.

Lake entry and residence - During lake residence, juvenile sockeye salmon production is limited by predation and potentially by the seasonal availability of their prey. Predators eat fry as they pass through shallow water habitats into the lake (Beauchamp 1990, Beauchamp et al. 1992, Tabor et al. 1998, Muckleshoot Indian Tribe, unpublished data). Although many fry move directly offshore, some utilize nearshore regions until mid spring (Martz et al. 1996 a, b). Smaller (total length < 250 mm) cutthroat trout were the most important nearshore predators (Nowack 2000), but yearling coho salmon, and rainbow trout also eat sockeye fry. All fry eventually move offshore in mid spring and reside for several months exclusively in the offshore zone of the lake. Larger (total length > 250 mm) cutthroat trout are the most important offshore predators (Beauchamp et al. 1992, Beauchamp 1994, Nowack 2000) throughout the peroid of lake residence. Northern pikeminnow (Eggers et al. 1978, Brocksmith 1999), and perhaps yellow perch impose lower, but potentially significant predation losses in the lake. Large (total length > 125 mm) prickly sculpin are potentially significant benthic predators on juvenile

sockeye salmon in the lake at various times of the year (Eric Warner, Muckleshoot Indian Tribe, unpublished data).

The lake rearing phase is filled with complex interactions among predators, competitors, and prey, which strongly influence survival and production of sockeye smolts (Figure 4), and are intimately tied to the history of water quality in the lake. The lake rearing environment has become more productive since the emergence of *Daphnia* as the predominant zooplankton species in the mid 1970s. Compared to other zooplankters, *Daphnia* graze phytoplankton at a higher and more efficient rate; consequently, the population increases much more rapidly in spring and can often "out-reproduce" the consumption rate by their predators. *Daphnia* are currently the primary prey of juvenile sockeye salmon (Chigbu and Sibley 1994). *Daphnia* had historically been excluded from the lake; first by a small predatory shrimp, *Neomysis mercedis* (Murtaugh 1981 a,b),

Figure 4. Food web relationships and interactions in Lake Washington. Dotted lines represent unknown interactions, width of arrow represents strength of interaction.

which move up into the water column at night to selectively feed on *Daphnia,* and later by the filamentous bluegreen alga, *Oscillatoria rubescens,* which mechanically inhibited the daphnids' ability to filter-feed (Edmondson and Litt 1982). *Neomysis* predation is believed to have prevented *Daphnia* populations from becoming established when water quality was reasonably good before the 1950s. Then the period of cultural eutrophication stimulated high densities of *Oscillatoria rubescens* during the 1950s through mid 1970s. Meanwhile, longfin smelt and juvenile sockeye salmon populations increased through the 1960s, adding two important species of small-bodied, pelagic, planktivorous fish. Smelt fed heavily on *Neomysis* in the pelagic zone, resulting in an estimated 90% reduction in *Neomysis* abundance by the late 1960s (Eggers et al. 1978). After the final sewage diversions were completed, *Oscillatoria rubescens* declined precipitously during the early 1970s. The establishment of *Daphnia* coincided with the decline of *Oscillatoria rubescens* and the continued control of *Neomysis* by smelt (Edmondson and Litt 1982; Edmondson and Abella 1988). Lake transparency of the pre-eutrophication period was achieved by the early 1970s (Secchi depth 3 m). When *Daphnia* emerged as the predominant zooplankter in the lake in 1975 (Edmondson and Litt 1982), lake transparency had doubled (Secchi depths of 6-7 m) because of their explosive reproductive rates and grazing efficiency. In addition to *Neomysis* and juvenile sockeye salmon, *Daphnia* became the primary prey of juvenile rainbow and cutthroat trout, steelhead smolts, age-0 smelt (in autumn only), threespine stickleback, and age 0-1 yellow perch (Beauchamp 1996).

Sockeye salmon production is influenced significantly by the longfin smelt population, which occupies a strategic position in the Lake Washington food web. Smelt are important prey of the top predators in the lake (cutthroat and rainbow trout, northern pikeminnow), but they also maintain predatory control over *Neomysis* in the upper pelagic zone. Recall that predation by *Neomysis* had previously excluded *Daphnia* from the lake. When smelt are abundant, they reduce *Neomysis* predation on *Daphnia*, and absorb much of the predation by cutthroat and rainbow trout and northern pikeminnow (Beauchamp 1994). However, longfin smelt spawn and die after two years and exhibit a two-year cyclic abundance pattern. A rainbow trout stocking program (initiated in 1980 and terminated in the late 1990s) amplified these cycles such that even-numbered year classes became 5-15 times more abundant than odd year classes (Beauchamp 1987, 1994; Chigbu 1993). The piscivore, planktivore, and *Neomysis* populations were tightly linked; when abundant age-1 smelt from even year classes were available, *Neomysis* populations exhibited 10-fold reductions, while lake-phase mortality rates for smelt and sockeye declined by 50% compared to when weak, odd-numbered year classes of smelt were present (Beauchamp, unpublished data).

Sockeye salmon are vulnerable to significant predation losses throughout the lake-rearing phase, and predation is strongly related to their overlap with predators occupying various depths and habitats through time (Beauchamp 1994). Based on the recent studies, cutthroat trout are now the most important predators on smelt and juvenile sockeye salmon in Lake Washington, consuming all available sizes throughout the year. Rainbow trout concentrate heavily on smelt year-round, only incidentally eating sockeye fry migrating into the lake while consuming prespawning adult smelt staging off the Cedar River. Northern pikeminnow move offshore and feed heavily on pelagic sockeye and smelt during autumn and winter. Both smelt and juvenile sockeye either remain deep (below 30 m) or forage in schools at intermediate depths (12-20 m) during daylight. At dusk, those in deep water rise while the schools in the intermediate depths disperse; however, juvenile sockeye salmon remain at intermediate depths while smelt ascend to the upper 10 m of the water column during the dusk and night periods (Beauchamp et al. 1999). These movements are reversed at dawn, and both species resume their daylight distribution patterns (Beauchamp 1994). The diel movement patterns lead to similar high vulnerabilities for smelt and sockeye to midwater predators like cutthroat trout (modal depth of 15 m) and northern pikeminnow (10-20 m deep in fall and winter), whereas only smelt are vulnerable to surface-oriented rainbow trout. Both cutthroat trout and northern pikeminnow can easily switch from smelt to juvenile sockeye salmon or other juvenile salmon when smelt year classes are weak. Rainbow trout are no longer stocked in Lake Washington, which should reduce the cyclic fluctuations of smelt, although the current status of the smelt population is unknown. The abundance of cutthroat trout, the most important juvenile salmon predator, has increased dramatically since the 1970s, while northern pikeminnow have shown only modest changes in abundance and size structure (Brocksmith 1999).

More recently, prickly sculpin have been discovered as a potentially important predator on juvenile sockeye salmon in the lake. Sculpins represent 80% of the fish biomass in the Lake Washington system (Eggers et al. 1978). They are distributed ubiquitously across the bottom of the lake, and larger individuals have been observed with presmolt-sized sockeye in their stomachs (E. Warner, Muckleshoot Tribal Fisheries Biologist, personal communication). Since prickly sculpin represent such a large biomass in Lake Washington, the predatory fraction of this population could impose significant losses of sockeye and other juvenile salmon. Fish prey represented 5% of the diet in 61-120 mm sculpin, and 29% in sculpin >120 mm (Rickard 1978).

Smolt migration through the ship canal and locks - Low smolt to adult return survival has been reported for Lake Washington sockeye. Only about half the smolt to adult survival rate observed among other sockeye systems has been reported for Lake Washington sockeye, which is curious given the size advantage of Lake Washington smolts. Lower survival may be associated with smolt condition or with out-migration circumstances past the Ballard Locks. Sockeye smolts, migrate through the ship canal and adjoining waters through the Montlake Cut, Lake Union, and Chittenden Locks to saltwater, distribute and feed through the North Pacific, then return past the locks in early summer, generally two years later. Smallmouth bass, and northern pikeminnow to a lesser extent, are the primary predators on juvenile salmon migrating through this corridor in spring and early summer (R. Tabor, USFWS, Olympia, unpublished data). The U.S. Army Corps of Engineers has a series of research projects and remedial construction projects underway to improve passage survival of juveniles and adults at the locks (F. Goetz, U.S. Army Corps of Engineers, Seattle, reports and unpublished data).

Timing and fitness differentiation - A major element in overall survival success of Lake Washington sockeye that is generally overlooked is the affect that the extended emergence pattern has on the fitness of the respective population segments. On the average, timing of emergence is related to the subsequent survival advantage of the different emergence segments. Under ideal circumstances, peak emergence has the greatest survival potential in the respective system, the extremes have correspondingly

lower survival potential, and no survival potential exists for emerging fry anytime over the rest of the year. In the case of sockeye in the Cedar River, with such a broad range in emergence timing, there will be a concurrent range in relative survival of emerging fry from those segments, which ultimately translate into differences in adult return potential. The curve showing the daily pattern of emerging fry (Figure 5), therefore, also represents

Figure 5. General weekly percent emergence of wild and hatchery sockeye fry emerging from the Cedar River.

the relative fitness of the emerging segments. The highest abundance represents the highest fitness or the optimum survival opportunity, and is thus associated with the adult temporal segment having the most numerous spawners. Given such a relationship, those fish outside the optimum timing have survival reduced in proportion to the distance they emerge from the optimum. If less than 20% of the population is represented in peak fry emergence timing, then less than 20% enjoy optimum fitness, with the remaining tapering off eventually to near 0 in either direction. Lower fitness of the members within a segment of the population can result from timing asynchrony with lake rearing conditions, but adverse migratory or spawning conditions (Gilhousen 1990) could also be contributing factors.

The point is that the emergence curve is a reflection of the relative fitness of various temporal segments of the population, demonstrated by relative contribution of reproducing adults. The decrease in fitness that extends from the peak emergence over the broad range of lake-entry timing can represent a significant source of mortality in the Lake Washington system. The extended range in spawning and emergence in the Cedar River has been more forgiving in Lake Washington due to the high productivity that existed in the lake as the population rapidly expanded from the 1960s. However, as the population approaches equilibrium with the carrying capacity of the lake, the pattern of extended lake entry timing is expected to narrow around the optimum through intraspecific competition and depensatory predation. However, as long as the more extreme temporal segments are given some level of advantage from time to time, such as the exceptionally early or late onset of spring, their existence in the ecosystem will continue, but at a cost proportional to their mean fitness.

The other purpose of this discussion on the relative fitness among temporal segments of the population is that population structure and its ultimate form are critical factors that need to be considered in sockeye hatchery management strategy. It is our belief that the Lake Washington sockeye population is not presently at equilibrium with the lake's carrying capacity, and given that interpretation it is important to understand the potential implications of the hatchery plan that intends to maintain representation of the spawning segments of the present run. Hatcheries can inhibit evolution of population structure by perpetuating the forms that exist at the time artificial production begins. Under such a strategy, it would be expected that the overall survival of hatchery incubated fry would be lower than if just peak spawners were used as broodstock, and this needs to be understood when assessing the success of the hatchery program.

Incubation hatcheries can also alter fry survival success by using temperatures different from those associated with the natural incubation conditions. The timing of lake-entry is the most important factor for success of sockeye enhancement when using fry releases. If emergence timing of hatchery fish is different from the natural population, then survival of the hatchery fish will be proportionally lower by the degree they differ in temporal fitness from peak emergence. The timing of fry releases from the experimental hatchery on the Cedar River is an example. On the average hatchery fry have been released nearly five weeks earlier than peak emergence of the wild counterpart (Figure 5). River entry timing of experimental hatchery fry, therefore, corresponded with the earlier segment of natural emergence and would experience proportionally lower fitness to the degree they were asynchronous with optimum timing.

Cyclic dominance - One potential problem that can occur when a sockeye ecosystem reaches equilibrium is cyclic dominance, or the dominance of one brood cycle over the other brood cycles returning in substantially lower numbers. It appears that most major sockeye systems demonstrate cyclic dominance when juvenile population approaches some abundance threshold in the system. The problem is that in sockeye systems that are largely on a quadrennial population cycle, it can lock the system into a cyclic pattern from which it is hard to escape. The quadrennial pattern of Fraser River sockeye populations is the best example. It may arise only to the extent that a dominant brood will exist with sub-dominant broods represented at some reduced abundance, but in some lakes dominant broods arise at the near exclusion of off-cycle representation. Lake Washington sockeye show some age class diversity, with age-5 fish representing up to 30% of broodyear spawners. Such high representation of multiple year classes from a given brood can reduce the effect of dominance. However, the tendency for sockeye systems to assume a cyclic pattern needs to be given consideration in the production goals of the hatchery, and it has to be a factor in the assessment of hatchery program success. The cyclic pattern, characteristic of most productive sockeye lakes, has not yet become apparent in Lake Washington, possibly because lake productivity has been able to sustain the present needs of the growing population. Also, predator populations appear to have either lacked the species composition or lagged in their own abundance to curtail the rate of sockeye population growth thus far.

Unknowns related to genetics and population dynamics - There are several uncertainties related to the genetics and population dynamics associated with the artificially propagated sockeye in the Lake Washington system. The influence of flow and the spawning ground abundance will have an influence on egg to adult survival in the Cedar River (Stober and Graybill 1974, Stober et al. 1978a, Stober et al. 1978b, Stober and Hanalainen 1978, 1980), as demonstrated in other systems, but the extent of such variability can only be approximated. Even the risks or benefits experienced by wild fry from proportionally large numbers of hatchery fry are unknown at this point, except for the long-term success of the sockeye spawning channels on the Fraser River (IPSFC). Incubation success of eggs in spawning channels is proportional to that expected from the Cedar River incubation hatchery, and no negative effects have been noted.

The reproductive success and recruit-per-spawner (R/S) relationships for hatchery-origin adults spawning naturally in the Cedar River relative to their natural-origin counterparts is expected to be the same as wild fish, and is the general working hypothesis assumed for the Cedar River hatchery returning adults resulting from newly emerged fry releases. However, concern about such an assumption has risen more recently where reproductive behavior of hatchery reared fish and captive broodstock has been observe less efficient than wild fish. While this is not anticipated to be a problem, monitoring and research on the potential problem is recommended in the report.

As the above discussion has shown, there have been significant irregularities in return success of Lake Washington for which there are several potential causes. The challenge to resolve these problems is a major undertaking and it is important to understand their resolution will not come just by increasing fry production. The hatchery program is expected to make a significant difference in the long-term stability of production, but the success of the sockeye population will depend on their interactions within the ecosystem, and must be evaluated in the context of sockeye life history within the basin. The Cedar River hatchery is a supplementation program. The natural population, therefore, establishes the template on which to guide hatchery operations. Monitoring the population and making sure the hatchery program adapts to the natural changes occurring in the population, without initiating those changes, will be a serious undertaking. The following section presents the guidelines that facilitated recommendations to minimize negative influences of the hatchery on the natural population.

Section II. General Guidelines for Conservation Hatcheries:

Notwithstanding the problems associated with hatcheries, which are recognized as potential risks in the use of such facilities, it is argued that hatcheries can also be a most useful tool for enhancement and supplementation if they are applied in the appropriate manner. Application of the hatchery concept, therefore, must be tailored to meet the needs of the target population. In the case of the Cedar River sockeye, it is the incubation environment that must be addressed both for mitigation purposes and production stability. Incubation facilities engender the least potential risk associated with application of hatcheries because only the portion of their early life history that precedes emergence or river entry are exposed to the artificial conditions, and in this case those conditions are not markedly different than the natural environment. The key is being careful that such applications fit into the biological template of the species targeted, and in the case of anadromous salmonids, especially sockeye, the incubation period can be most critical if it is out of synchrony with the environmental conditions that determine the nature of the template. Prerequisites associated with the general hatchery concept were included in a report by the Scientific Review Team (SRT) of the Columbia River Independent Scientific Advisory Board under the title, *Review of Artificial Production of Anadromous and Resident Fish in the Columbia River Basin* (Brannon et al. 1999). The review developed guidelines considered basic to the hatchery concept, and were corroborated by other similar independent reports on hatchery assessment (Flagg and Nash 1999, NRC 1998). Fifteen of the 20 specific guidelines presented in the SRT report apply to the Cedar River project, and are presented here as the basic reference used in the planning process for the sockeye hatchery.

Guideline 1. Technology should be developed and used to more closely resemble natural incubation and rearing conditions in salmonid hatchery propagation.

Twelve points were cited on the technology related to incubation and rearing conditions. The five listed below apply just to the incubation hatchery.

- *incubation in substrate and darkness*
- *incubation at lower densities*
- *minimize fish-human interaction*
- *acclimation ponds at release sites*
- *volitional emigration from release sites*

From among the five points listed, the first three elements apply to incubation conditions and the latter two to post-emergence release. These are critical components related to natural incubation habitat and emergence behavior that were considered for the hatchery plan. Low-density incubation is particularly applicable when IHNV is present in the population, but low-density incubation is also recommended for lower stress conditions created by favorable oxygen levels and irrigation efficiency. Sufficient imprinting opportunity at the release site and volitional emigration are necessary to provide the temporal synchrony in emigration and the appropriate return distribution of returning adults.

Guideline 2. Hatchery facilities need to be designed and engineered to represent natural incubation and rearing habitat, simulating incubation and rearing experiences complementary with expectations of wild fish in natural habitat.

As it applies to the sockeye hatchery plan, the second guideline reiterates the importance of natural-like incubation and emergence opportunity in hatchery incubators. The biological criteria are the points of concern, and the hatchery design, therefore, has to have the biological needs as top priority. Conceptually, it is suggested that incubation should occur in substrate, which will conserve energy for growth to maximize size at emergence, similar to what occurs under natural incubation environments. Also, volitional emergence from incubators should be the criterion for release into the Cedar River. Such provisions will require extensive effort to simulate a natural emergence pattern.

To maintain the eggs in isolation immediately after spawning, they should be kept in separate tray incubators until IHNV assays are complete, or to the advanced eyed stage if thermal marking is employed. After that point, the virus-free egg lots would be distributed to the incubators. Substrate incubators meet the natural incubation, emergence and dispersal requirements most effectively.

(Guideline 3 does not apply to the sockeye hatchery)

Guideline 4. To mimic natural populations, anadromous hatchery production strategy should target natural population parameters in size and timing among emigrating anadromous juveniles to synchronize with environmental selective forces shaping natural population structure.

Here the specifications for emergence timing and fry size emphasize the importance of imitating natural production. Behaviorally, negatively rheotactic fry emerge from incubation gravel and head to their nursery lake with the stream current. Artificially incubated fry, therefore, should be distributed to the river immediately upon emergence. Distribution at emergence means that no pre-release feeding will occur. Cedar River hatchery fry size at release should be the same size of newly emerged natural fry in Cedar River. Fry size is determined by egg size and energy priority during development under their normal ambient temperature regime. Here is where substrate offers one of its benefits; maximizing fry size from the finite energy stores available. Fry emerging from incubation without substrate can be as much as 40% smaller at yolk absorption as fry incubated with substrate (Brannon 1965). The difference is simply from the benefit of the reduced energy requirement for exercise in a confining substrate. Exercise is a high-energy priority, and growth is sacrificed to satisfy that requirement under conditions that induce swimming activity.

Guideline 5. To mimic natural populations, resident hatchery production strategy *should target population parameters in size and release timing of hatchery –produced resident juveniles to correspond with adequate food availability and favorable prey to maximize their post-stocking growth and survival.*

This guideline addressed resident fish, but it points out the importance of synchrony with the food supply, and in the case of sockeye it refers to the productivity cycle (primarily plankton) in the nursery lake. Lake Washington is a productive system, but large numbers of fry must be timed appropriately to match the major plankton bloom. By proportionally selecting spawners to represent the timing pattern of the spawning population, the appropriate temporal pattern for emergence would occur, given that temperatures in the hatchery match those of the river.

Guideline 6. Supplementation hatchery policy should utilize natal stream temperatures to reinforce genetic compatibility with local environments and provide the linkage between stock and habitat that is responsible for population structure of stocks from which hatchery fish are generated.

Temperature is the determining factor associated with adult sockeye spawning time and the fundamental influence on population structure. Under natural selection, adult spawning time evolved as feedback around the most effective emergence-timing pattern of the progeny. The hatchery should use the ambient temperature regime of the Cedar River, therefore, for the incubation temperature regime. One of the advantages of the proposed hatchery site is the pathogen-free groundwater supply. However, the groundwater doesn't represent the ambient temperature of the river and would accelerate emergence. To match the river temperature it will require a heat-exchange system with river water. With the volume of river water available, temperature adjustment should not be a problem. If slight temperature differences are required for eggs spawned from lower river fish, temperature should be adjustable in separate incubation basins by altering exchange exposure. Temperature control is critical for correct timing of emergence, and has to be the primary element modeled in the hatchery.

Guideline 7. Salmonid hatchery incubation and rearing experiences should use the natal stream water source whenever possible to enhance homestream recognition.

Incubation experiences in the natal habitat is critical for homing accuracy. One of the problems with conventional hatchery practices is that many use ground water for incubation. Spring water at Landsburg probably doesn't match homestream odor profile and this is a potential problem. Imprinting is sequential (Brannon and Quinn 1990; Quinn et al. 1990), and the incubation environment is the first odor cue on which alevins imprint and the ultimate identity sought by returning fish (Brannon 1982). To assure the continuity between hatchery fish genetics and local stream habitat, local water sources are necessary, which is not possible at the Cedar River

hatchery site because of IHNV risk. However, releasing fry in the vicinity of their determined return location is proposed to substitute for incubation in the actual stream. This is a compromise to accommodate the limitations of artificial propagation, and short-term acclamation at release sites may need to be included.

Guideline 8. Hatchery release strategies need to follow standards that accommodate reasonable numerical limits determined by the carrying capacity of the receiving stream to accommodate residence needs of non-migrating members of the release population.

Standards should include impact considerations on the wild fish residing in the system, and should be based on life history requirements of the cultured stock. With virus-free sockeye fry releases following the timing pattern of wild sockeye fry, the impact on resident stream dwelling fish is expected to be only positive. The target production of up to 34 million fry from the hatchery added to the natural emerging population is determined well within the rearing capacity of the lake. The sockeye/smelt interaction on plankton resources in the lake will need to be monitored, as well as the response of the smelt to large numbers of juvenile sockeye.

Guideline 9. Hatchery programs should dedicate significant effort in developing small facilites designed for specific stream sites where supplementation and enhancement objectives are sought, using local stocks and ambient water in the facilities designed around engineered habitat to simulate the natural stream, whenever possible.

The NMFS Conservation Biology Division suggests that Bear Creek sockeye may represent the historic population in the Lake, and that interaction with Cedar River hatchery sockeye could be harmful (gene pool dilution). They propose, therefore, that stray rates of more than two or three spawners should be the tolerable threshold that would place the upper limit on the annual production of hatchery fish. However, Bear Creek sockeye maintenance may best be addressed by supplementation of Bear Creek sockeye with a small supplementation program located on Bear Creek. This would allow screening of spawners to supplement with only those of the appropriate genetic origin, if they are in fact different. It is suggested that a portion of the mitigation funds could be dedicated to that purpose rather than limiting Cedar River production and putting the goal of the hatchery program in jeopardy.

Guideline 10. Genetic and breeding protocols consistent with local stock structure need to be developed and faithfully adhered to as a mechanism to minimize potential negative hatchery effects on wild populations and to maximize the positive benefits that hatcheries can contribute to the recovery and maintenance of salmonids in the ecosystem.

The correct seed stock is key to producing viable, healthy sockeye. It was stated by the SRT (Brannon et al. 1999) that *"Development and adherence to strict genetic guidelines and breeding protocols consistent with local population structure is essential for effective hatchery contribution to wild production and maintenance of local genetic diversity".* The matter that needs to be discussed under this guideline is what constitutes local

population structure and genetic diversity? If the population is presently in equilibrium, then a hatchery plan should attempt to represent the population proportional to the present abundance pattern. However, if the population is in the process of equilibrating, the hatchery program could lock the population in its present temporal range, and that would be less desirable for maximum fitness. As discussed previously, the fitness of the early and late extremes of a returning run is always marginal. It is expected that the present temporal pattern of the Cedar River population will naturally regress as their abundance stabilizes at a higher level. It will be necessary to carefully follow the pattern of return and attempt to match the temporal spawning pattern observed in the river to limit artificial alteration of such patterns.

The other pertinent element that has major implications in the hatchery program is the method of selecting brood fish. If weirs are used to intercept fish, it creates major problems that have to be overcome. Ideally the hatchery brood fish should represent temporal and spatial components of the population. It is difficult to know what spatial segment of the run is being targeted at a weir placed in the lower mainstem of a system. There is also the problem with retention of green fish because of crowding and self-inflicted abuse they experience while attempting to get past the barrier. Also, interference with other species is a concern of the NMFS Conservation Biology Division. The plan will accommodate these concerns by having weir operation on a schedule that will fish on the targeted segment of the run while allowing the rest of the run and other species to pass with little or no delay at the site.

Guideline 11. Hatchery propagation should use large breeding populations to minimize inbreeding effects and maintain what genetic diversity is present within the population.

The breeding population goal will approach 10,000 females which eliminates concerns about inbreeding and diversity within any segment of the run to be included in hatchery propagation.

Guideline 12. Hatchery supplementation programs should avoid using strays in breeding operations with returning fish.

Stock hybridization breaks down genetic homeostasis and disrupts adaptive linkages which lowers the fitness of the local stock. This can be a problem when few numbers of fish are used for broodstock. The problem will not be of concern in the Cedar River, and if a small station is developed on Bear Creek, screening would eliminate that concern.

(Guideline 13 does not apply to the sockeye hatchery)

Guideline 14. Germ plasm repositories should be developed to preserve genetic diversity for application in future recovery and restoration projects in the Basin, and to maintain a gene bank to reinforce diversity among small inbred natural populations.

This guideline may be given consideration as a mechanism to re-introduce genetic variation in Cedar River sockeye, should it be lost over the years in hatchery propagation. It would also provide a gene bank to maintain Bear Creek genotypes in the event that Bear Creek sockeye are distinct and become genetically swamped by Cedar River sockeye. Gene banks should be developed for all identifiable stocks of salmonid fishes for future application if such recovery tools become necessary. It is the least expensive security that can be applied in conservation management.

Guideline 15. The physical and genetic status of all natural populations of anadromous and resident salmonids need to be understood and routinely reviewed as the basis of management planning for artificial production.

Data collection and genetic analysis is occurring on sub-populations within the Lake Washington Basin. Collection of such data should be continued, and in addition to the traditional numerical status of the run, distribution patterns, size and timing of migratory, segments, and genetic diversity should be included in the monitoring program.

(Guideline 16 does not apply to the sockeye hatchery)

Guideline 17. A hatchery fish monitoring program needs to be developed on performance from release to return, including information on survival success, interception distribution, behavior, and genotypic changes experienced from selection between release and return.

Attention should also be given to descriptive genetic assessment at time of return to determine if genotypes surviving are representative of genotypes released, and compatible with the native stock. Otolith thermal marks applied prior to hatching or otolith oxytetratcycline marking applied to post-alevin stages should be considered for stock identification.

(Guideline 18 does not apply to the sockeye hatchery)

Guideline 19. Regular performance audits of artificial production objectives should be undertaken, and where they are not successful, research should be initiated to resolve the problem.

Regular performance audits of artificial production from the Cedar River hatchery and is addressed with the present Lake Washington evaluation studies, and will be a necessary activity to provide the type of information required for adaptive management.

Section III. Recommendations Specific to the Cedar River Hatchery:

The specific recommendations for the Cedar River sockeye salmon hatchery are presented in four categories: adult interception and incubation, genetics and population dynamics, fish health, and ecosystem dynamics.

A. Adult Interception and Incubation:

The general purpose of the Cedar River sockeye hatchery is to function as a supplementation facility. The hatchery will strive to integrate hatchery and wild segments of the run in a manner that minimizes the ecological and genetic impact to the naturally spawning population. To simulate the natural system, spawners will be intercepted in a manner to represent the natural timing. Eggs will be spawned and taken to the hatchery for incubation from which wild-like, un-fed fry will volitionally emerge and enter the river shortly thereafter. Un-fed, volitional fry releases will be most comparable to natural fry emigrating from the system and will minimize the impact of hatchery fish on wild fish. Maximum effort, therefore, will be placed on imitating natural life history patterns of resident sockeye from the time of egg take through release of fry.

The recommendations for the sockeye hatchery on the Cedar River address three specific phases of hatchery operations: adult interception and spawning, egg and alevin incubation, and juvenile release. The guiding principles, rationale, and associated recommendations are listed for each segment of the operation. The following sections, also include abstracted text from Flagg and Nash (1999) and identify the major culture strategies for the management and operation of the Cedar River sockeye hatchery, and outline potential protocols for culturing wild-like fish as well.

Recommendation 1. Spawners used for hatchery propagation should be representative of the natural population structure in both their temporal and spatial distribution.

It would be most desirable to take ripe fish off of their specific spawning grounds and thus identify the various segments of the spawning population with those locations for subsequent fry release. However, with the large number of eggs planned for hatchery propagation, such a method is not considered logistically feasible under the present circumstances. Therefore, the alternative approach recommended is to intercept a percentage of the fish over the duration of the spawning cycle in proportion to the abundance pattern of fish entering the system, and to hold them until they are ready to spawn. Although, return time may not be an accurate predictor of spawning time, especially during the first half of the run, interception of temporal segments of the run will be the criterion followed since preserving those segments will be part of the conservation goal and will ultimately capture the spawning variability of the run.

Interception will require a weir and trap as close to the river mouth as possible. Facilities for holding and spawning of adults should be located at the trap site to consolidate the operations and reduce stress from extensive handling. It is desirable to have a permanent weir platform on which inclined collapsible weir panels can be secured. During trapping sessions the panels would be raised to stop the fish, and between trapping sessions the panels would be collapsed and laid against the platform floor, allowing adults to pass upstream unobstructed.

The weir platform should follow a diagonal line across the river, with the trap located at the upstream end of the diagonal. At least two holding chambers or ponds should be built on secure footings adjacent to the site, and the trap fixed with a floor (brail) that can be raised to discharge fish and water into a sluice-way leading to the holding facilities. The holding ponds will be flushed with river water continuously when in operation and should have crowders to concentrate fish for examination of readiness for spawning. Water temperatures during the early part of the run may create conditions in the holding facilities undesirable for good adult health and successful maturation. To guard against such circumstances, it is recommended that ground water be acquired and mixed with the river water to assure appropriate holding temperatures for fish maintenance. If that is not possible, then adult holding facilities may be necessary closer to Landsburg where cooler temperatures are available. A volitional spawner reach (elevated riffle within the holding facilities) that ripe fish would ascend when ready to spawn is not recommended because it is assumed that all these fish will remain in a migratory state.

Anesthetic tanks and a covered spawning building would be included as part of the holding facilities. All fish would be anesthetized to determine spawning readiness, and the ripe fish killed for spawning. The site and facilities will be permanent to provide the most secure and least intrusive access to spawners. Carcasses free of IHN should be distributed to locations in the river below Landsburg. Adult treatment and breeding protocols are covered in the fish health and genetics sections.

Recommendation 2. Hatchery incubation technology should be applied to produce fry comparable to the outmigration timing, size, and quality of wild fry emerging in the river.

Olla et al. (1995, 1998) suggested that fish reared in a psycho-sensory-deprived hatchery environment are less able to carry out the most basic of all survival skills: to eat and not be eaten. Providing animals with more complex rearing habitats that approximate natural conditions is an increasingly popular method for improving the well-being of animals in captivity. Hatchery technology, therefore, should provide incubation (and rearing if and when appropriate) vessels with options for habitat complexity that promote a more wild-like appearance and behavior among juveniles. In those instances if and when rearing is employed, densities should be maintained to more closely simulate natural spatial distributions. These precautions are expected to reduce many environmentally-influenced differences between cultured and wild fish, and improve their post-release survival by decreasing stress, reduce domestication, and acclimate fish more appropriately for natural post-release conditions.

In nature, salmonid eggs incubate and alevins develop in the darkened matrix-rich environment in the gravel substrate of the redd. Lack of substrate and excess extraneous light, which often occur in the hatchery environments, induce excess alevin movement with an increase demand on energy stores that results in smaller fry at emergence. In some wild stocks these conditions may induce pre-emergence death, but most certainly they result in lower post emergence survival compared to their wild counterparts. Understandably, the primary mechanism for poorer survival is the size disadvantage discussed previously. Smaller sockeye fry at emergence remain susceptible to size-specific predation longer during their lake residence period and experience the same size disadvantage that kokanee fry experience in competition with larger sockeye fry. Hatchery incubation environments that used gravel or artificial matrix substrates, such as plastic bio-rings, saddles, or mesh, produced substantially larger fry (Brannon 1965, Poon 1977, Leon and Bonney 1979, Murray and Beacham 1986, Fuss and Johnson 1988). Those with darkened incubation environments also produced fry considered more responsive to new experiences (Poon 1977, Mighell 1981), which will provide survival benefits to the fish when experiencing their first exposure to natural daylight and predator challenges.

The details associated with incubation include the following elements.

- eggs initially incubated in isolation trays
- prior to hatching the eggs transferred for incubation to a suitable substrate
- egg densities kept low to provide un-crowded alevin incubation
- substrate size to provide 3-dimensional distribution of alevins
- incubation to take place under ambient river temperatures
- irrigation flow through substrate to be well distributed
- inflow/outflow oxygen differential not to exceed 2 ppm
- volitional emigration permitted into collection basins
- collection basins to be linked to any combination of incubators

The type of incubators used at the Cedar River sockeye hatchery is left to the discretion of the hatchery operators. The panel recommendations are directed at the quality of the fry produced by the hatchery. Fry quality in the context of this program is a criterion based on their condition at the time of emergence. Fry condition is defined in three ways: their behavior, size, and condition index. Behaviorally, the fry should be photo-negative and should have experienced no exposure to any circumstances except darkness and contact with substrate prior to emergence. As unfed fry, their size should be comparable to the wild river fry, or averaging approximately the same wet weight as their original egg weight. The mean condition index (kD) at emergence should match that of wild fry (1.75 to 1.95). The incubator design, therefore, should assure that fry quality meets these criteria. Measures to address disease concerns during incubation are covered in the fish health section.

Size is also a factor at other life history phases. When the objective is to supplement the wild population, precautions have to be taken during rearing to eliminate size discrepancies with wild fish. Under rearing programs the opposite problem usually exists, with the cultured fish growing faster in captivity than fish in the wild, and becoming much larger than their wild counterparts. The risk in releasing large fish from production hatcheries is that they may out-compete the wild conspecifics they are meant to supplement. This is because in intra-specific contests over food and space, all else being equal, the largest fish usually win (Hoar 1951, Chapman 1962, Mason and

Chapman 1965, Jenkins 1969, Noakes 1980, Abbot et al. 1985, Maynard 1987). Therefore, in those instances if and when the Cedar River sockeye hatchery should rear fish to the fingerling stage, the size objective at release should be based on the size of naturally produced fish at that life history stage. The rationale is that the likelihood of hatchery fish dominating wild individuals in competitive encounters will be reduced if they are similar in size. This is not simply a ration size control strategy because the condition factor and energy reserves of hatchery fish at release should approximate that of their wild counterparts, making temperature another control element. In the case of the very extended emergence period demonstrated by Cedar River sockeye, it will be necessary to keep track of the temporal segments of the run and to match the size of the wild segments represented by the cultured units. Ration control will have to be used in such circumstances, but under the appropriate temperature control regime to synchronize size with condition.

Rearing density also becomes a major factor in artificially cultured units from the standpoint of fish health and body condition. The effect of rearing density on fry quality and subsequent adult returns appears to be quite species specific, and may be related to disease interactions which occur long after release from the hatchery. The optimum density for the rearing juvenile salmonids in hatcheries will be influenced by a number of physiological, behavioral, and disease factors. For some species, such as spring chinook, high densities trigger outbreaks of disease. In such cases rearing densities should be below those normally used. Working with chinook salmon in salt water, Mazur et al. (1993) found the presence of bacteria (bacterial kidney disease or BKD), in the kidneys was directly proportional to rearing density. In addition to known physiological results of crowding, which can affect the ability of fish to resist infection, direct ingestion of fecal matter was observed during feeding. Because of the high loads of bacteria in fecal matter from infected fish, it was hypothesized that horizontal transmission of BKD may be more prevalent at higher density.

Similarly, because of the potential for outbreaks of IHNV the Cedar River sockeye hatchery should use low incubation (rearing) densities that more closely approximate wild conditions to reduce the risk of disease and to improve juvenile survival during the culture experience. The latent effects of IHNV are not well understood and actions recommended under the fish health section are of utmost importance to the success of the sockeye hatchery.

Recommendation 3. Juvenile releases should represent the temporal and spatial distribution of the naturally emerging fry produced in the Cedar River.

Emergence and out-migration behaviors are under a level of genetic control (Brannon 1973, Clarke et al. 1994) and have been shaped within each population by evolutionary processes that adapt salmon to their environment. Healey (1994) pointed out that the variation within individual populations of salmon is a strategy to utilize a range of habitat types and, perhaps, reduce the risk of catastrophic mortality in an uncertain environment. Strategy in this sense is better defined as life history patterns that are selectively beneficial often enough to have been maintained in the population. Thus, many Pacific salmon populations have evolved an emergence and out-migration pattern that produce emerging or migrating fish over a wide range of times and ages. This pattern ensures that some members of each year class will encounter the best mix of food and prey conditions, and experience the survival benefits of such synchrony. Although the synchrony between the environment and temporal segments of the emerging or out-migrating fish will vary from year to year, they will remain represented in the population as long as the advantage of those segments is sufficiently frequent to sustain the phenotype. Such variation in behavior enables the population to persist in an unpredictable environment. Allowing hatchery fish multiple release windows to out-migrate on their own volition will maintain this genetic variation within the population.

Therefore, it is recommended that fry be allowed to volitionally emigrate from the incubation hatchery to the river. The key assumption of volitional release is that fish will not leave the incubation substrate until conditions are optimum for subsequent survival as newly emerged fry. This is also believed true at other life history stages such as smoltification. Until certain physiological processes trigger their downstream migratory behavior, survival of fish released to the river out of such synchrony would be negatively affected under most conditions (Brannon et al. 1982, NRC 1996, Kapuscinski 1997, Brannon et al. 1999). The rationale is simply to provide windows of opportunity for emerging and out-migrating fish that allow the natural expression of volitional behavior in synchrony with the wild populations.

Fry emerging into the hatchery collection basins from any combination of incubators should be transported immediately to the river upon emergence and never delayed beyond 24 hours of the event. Distribution of fry will be by tank truck to predetermined locations in the river based on the spatial/temporal pattern of spawners observed as the mean distribution over several years. Transfer of fry will occur during hours of darkness. In essence, fry from eggs taken from the different segments of the run will be released on the night of their emergence at river locations approximating the sites represented by the temporal segments of their parents. Monitoring will be required to ensure that fry release sites approximate the spatial/temporal distribution of their parents. If a non-random distribution exists, the panel assumes it will be temperature related, and the homing of adults resulting from hatchery-produced fry should be to those river locations associated with the temperature regime. Random spawner distribution over the river is unlikely, but if a random distribution of spawners exists, then fry should be released from all release sites in proportion to the distribution of spawners over the length of the river. Details on determining the temporal distribution are covered in the monitoring plan.

Recommendation 4. To maximize imprinting opportunity and reduce straying, juvenile sockeye salmon must experience the odors of their natal system at various times and physiological states so the odors can be learned.

Before out-migration, juvenile salmon learn odors associated with their natal streams, which guide their homing migrations as adults. Homing behavior of salmon produced in hatcheries is extremely variable, and many returning adults stray; some species more than others. Straying of sockeye salmon reared in the Cedar River sockeye hatchery would represent a level of threat to native stocks that might exist in other tributaries of the Lake Washington watershed. Incubating (or rearing) and releasing juvenile salmon in water from their intended return location has the greatest potential to minimize straying

Imprinting in salmon may occur at multiple life history stages. It is well known that olfactory imprinting occurs during sensitive periods associated with surges in plasma thyroxine levels during parr-smolt transformation (Dittman et al 1995). However, in a number of stocks of Pacific salmon species (e.g., sockeye and stream-type chinook) parr-smolt transformation may occur downstream from incubation and early-rearing habitats (Groot and Margolis 1991), but returning adults migrate past areas where they underwent transformation and return within close proximity of their natal habitat. This indicates that there are more than one imprinting period in which home sites are encoded.

To maximize imprinting opportunity, juvenile salmon must experience the odors of their natal system at various times and physiological states so the odors can be learned. When this is not possible, a period of acclimation in the intended return water should improve imprinting and homing. In order to reduce straying, the Cedar River sockeye hatchery should adopt practices such as off-site acclimation prior to release, and other promising imprinting or homing techniques.

Recommendation 5. The hatchery should program production releases to accommodate the natural spatial and temporal patterns of abundance in wild fish populations.

The Cedar River sockeye hatchery production strategies will have to follow data collected on lake productivity and fry distribution to assure that numbers of hatchery-produced juveniles will not exceed the carrying capacity of Lake Washington environments used by sockeye.

B. Genetics and Population Dynamics:

The Cedar River sockeye salmon hatchery will function as in integrated hatchery-wild system. Under this system, hatchery-produced fish and naturally-produced fish will be treated as a common gene pool. The hatchery will be viewed as an artificial extension of the natural habitat where fertilization rates and egg-to-fry survivals in the hatchery will be substantially greater than the counterpart rates in the Cedar River.

We anticipate that the Cedar River hatchery will retain between 5% and 50% of the total number of adults entering the Cedar River each year depending on predicted escapement levels (Table 1). The Cedar River hatchery will have a capacity to produce 34 million fry. To meet this goal, approximately 11,000 adult females will need to be trapped each year. A maximum of 11,000 males would also be retained for broodstock, although 5,500 males would be sufficient to satisfy genetic concerns. Total escapements to the Lake Washington watershed since 1971 have varied from 26,000 fish in 1995 to 435,000 fish in 1977 (WDFW sockeye salmon database). As noted below (*Recommendation 8*), we are recommending that a maximum of 50% of the total number of returning adults be retained for broodstock. This 50% restriction would only be necessary when predicted escapements to the Cedar River are less than 40,000 fish. If the total predicted escapement the Cedar River is less than 10,000 fish, then we are suggesting that all adults might be spawned in the hatchery as a conservation measure. We defer to the co-managers for decisions regarding percent allocation of adults to the hatchery and natural spawning if predicted escapements are 10,000 to 20,000 fish (see Table 1).

The escapement goal for the Cedar River is 300,000-350,000 adults. In years where the goal of 350,000 fish is achieved, we would expect approximately 50% (range = 28-76%) of the adults to be of hatchery-origin if one assumes fry-to-adult survivals for hatchery fish are equal to those of naturally-produced fish (Table 1). On the other hand, we expect fry-to-adult survivals to be less for hatchery fish than for their wild counterparts (Table 2). If the mean fry-to-adult survival for hatchery fish is one-half that of wild fish (0.45% versus 0.9%, respectively), then (a) the R/S ratio for hatchery-produced fish would be 7.0 (versus a mean of 1.28 for wild fish) and (b) hatchery-origin adults would constitute approximately 25% (range = 13-37%) of the total number of returning adults if escapement goals are maintained.

However, it may be difficult to achieve the desired escapement levels for fish of particular brood years because the number of naturally-produced outmigrant fry per adult spawner in the Cedar River fluctuates widely depending on water flows and the severity of winter storms during the period that eggs are incubating in the gravel. For example, the estimated number of naturally-produced fry per spawner in the Cedar River ranged from 33.2 fry/adult spawner in 1995 (peak flow = 7,310 cfs) to 271.0 fry/adult spawner in 1992 (peak flow of 1,570 cfs) during brood years 1991-1996 (Seiler and Kishimoto 1997). The Cedar River apparently suffers from extensive gravel scouring during high flows, thus reducing overall egg-to-fry survival for those brood years. In contrast, egg-to-fry survivals at the time of release from the existing Landsburg facility averaged 91.9% and ranged from 88.2% to 94.3% during brood years 1991-1999.

Table 1. Number of sockeye retained for broodstock and estimated number of hatchery- and naturally-produced fry as a function of predicted run size to the Cedar River.

Escapement	**No. of hatchery adults**		**Predicted number of fry produced**		
(No. of adults)	**females**	**males**	**hatchery**	**wild**	**%hatchery**
10,000	5,000	5,000	15.5M	0	100%
10,000-20,000	?	?	?	?	?
20,000	5,000	5,000	15.5M	330K - 2.7M	83-98%
30,000	7,500	5-7,500	23.2M	495K - 4.1M	85-98%
40,000	10,940	5-10,000	34.0M	660K - 5.4M	86-98%

50,000	10,940	5-10,000	34.0M	990K - 8.1M	81-97%
100,000	10,940	5-10,000	34.0M	2.6M - 21.7M	61-93%
200,000	10,940	5-10,000	34.0M	5.9M –48.8M	41-85%
300,000	10,940	5-10,000	34.0M	9.2M - 75.9M	31-79%
350,000	10,940	5-10,000	34.0M	10.9M - 89.4M	28-76%
400,000	10,940	5-10,000	34.0M	12.5M -103.0M	25-73%

Note: The hatchery will have a capacity to release 34 million (34M) fry. The mean fecundity (number of eggs) per female spawner was 3,590 eggs/female in 1999 and 3,176 eggs/female in 1998. This results in an overall mean fecundity of 3,382 eggs/female. The mean egg-to-fry survival for brood years 1991-1999 at the existing Landsburg facility was 91.9% (range = 88.2-94.3%). Thus, at full capacity, the hatchery will need to retain approximately 10,940 females to produce 34 million fry. In contrast, the mean estimated number of naturally-produced fry per female spawner in the Cedar River for brood years 1991-1996, assuming a 50:50 sex ratio for natural spawners, was 286 fry/female with a range of 66 to 542 fry/female in high (7,310 cfs) and low (1,570 cfs) flow years, respectively (Seiler and Kishimoto 1997). The predicted number of wild fry below is based on (a) the number of females allowed to spawn naturally after the indicated number of females are retained for the hatchery and (b) the expected range of the number of wild fry produced per naturally spawning female (66-542 fry/female). For years in which escapement levels are less than 100,000 adults, hatchery fry for the resulting brood year would constitute the vast majority of fry produced in the Cedar River basin. The escapement goal for the Cedar River is 300,000-350,000 adults. At those escapement levels, hatchery-produced fry for the resulting brood year are expected to constitute approximately 50% (28 -79%) of the total number of fry produced in the Cedar River. If fry-to-adult survivals for hatchery-origin fish are similar to those of wild fish, then we would expect hatchery-origin to constitute similar percentages among returns.

Each year and each generation, a random portion of the gene pool (approximately 5-50% depending on total run size) will be spawned in the hatchery while the remaining portion (50-95%) will be allowed to spawn naturally in the Cedar River (Table 1). Natural-origin and hatchery-origin adults will be incorporated into the hatchery broodstock each year in proportion to their occurrence among all adults returning to the Cedar River. This management strategy should maintain genetic continuity between the hatchery and wild environments. If escapement goals are maintained, then at least 50% of the returning adults each year should be natural-origin adults (Tables 1 and 2). These predicted outcomes assume that hatchery-origin adults not retained for broodstock will reproduce successfully in the Cedar River at a rate comparable to their natural-origin counterparts. This is a critical assumption on which the numbers in Table 2 are based. This assumption thus needs to be tested via research.

Table 2. Predicted (mean) spawner recruit relationships for females spawning naturally in the Cedar River versus females spawning artificially in the Cedar River hatchery as a function of varying fry-to-adult survivals for hatchery-produced fry.

Mean #eggs/female	Egg→Fry Survival	Mean #fry/female	Fry→Adult Survival	Mean #adults	R/S
			Natural spawners		
3,382	8.5%	286	0.90%	2.56	1.28
			Hatchery spawners		
3,382	91.9%	3,108	0.90%	28.0	14
3,382	91.9%	3,108	0.80%	25.0	12.4
3,382	91.9%	3,108	0.50%	15.5	7.8
3,382	91.9%	3,108	0.45%	14.0	7.0
3,382	91.9%	3,108	0.10%	3.1	1.6

Note: Fry-to-adult survivals and R/S relationships for adults spawned artificially at the existing Landsburg facility have not yet been estimated pending WDFW's reading of otoliths collected from trapped adults. The numbers shown above are based on (a) a mean number of 3,382 eggs per female, (b) mean values of 3,108 and 286 fry produced per female for hatchery and natural spawners, respectively, and (c) a mean number of recruits-per-natural spawner in the Lake Washington watershed of R/S = 1.28 based on brood years 1967-1991 (WDFW sockeye salmon database). The mean value of R/S = 1.28 was used to calculate a mean fry-to-adult survival of 0.90% for fish that are the product of natural spawning. Fry-to-adult survivals for hatchery-produced fish are assumed to be less than or equal to those of wild fish. A mean fry-to-adult survival for hatchery fish that is one-half the mean estimated value for wild fish would yield, on average, 7.0 adult recruits per hatchery spawner the previous generation. Thus, based on the latter value of R/S = 7.0 and approximately 11,000 females spawned in the hatchery, we would expect the Cedar River hatchery to return approximately 150,000 recruits per year. Variation from this latter number will largely reflect variation in fry-to-adult survivals for hatchery-origin fish, which are unknown at this time for the existing Landsburg facility. The numbers above assume a 50:50 sex ratio.

Like all hatchery programs, the proposed Cedar River hatchery will potentially pose two genetic risks to naturally spawning populations: (1) risks to the existing genetic structure of naturally spawning populations in the Cedar River and (2) risks to naturally spawning populations in other areas of the Lake Washington watershed due to potential straying of hatchery-origin adults. Of principal concern is the potential straying of hatchery fish into Bear Creek, a tributary to the Sammamish River at the north end of Lake Washington. Bear Creek currently supports an alleged genetically distinct population of sockeye salmon; however, it is unknown whether this population represents a native population derived from kokanee or a genetically-diverged population derived from sockeye salmon transplants (Gustafson et al. 1997).

Recommendation 6. The target population for hatchery enhancement within the Cedar River must be specified spatially and temporally.

Adult sockeye salmon will be intercepted by a weir for collection of broodstock. Although the time (i.e. week) of arrival of each fish retained for broodstock can be recorded and maintained on those fish prior to spawning (e.g. via external tags), the relationship between run-timing (arrival at the weir) and potential spawning location within the Cedar River is unknown. Any spatial genetic structuring of sockeye salmon populations upstream from the weir in the Cedar River could potentially be reduced as a result of the hatchery program. On the other hand, spatial genetic structuring within the Cedar River may not be compromised significantly if such structuring is strongly correlated with spawn date. Such a correlation would occur, for example, if early-spawning fish spawned primarily in the upper portions of the watershed while late spawning fish spawned primarily in the lower portions of the watershed. Answering this question is an important research need. Moreover, it will be possible to determine the temporal/spatial genetic relationships among spawning aggregations within the watershed by trapping and tagging representative portions of the various temporal segments of the run (e.g. operating the trap only 1 or 2 days per week) passing the weir to observe where they spawn upstream. These data will help guide and adjust the broodstock interception process.

Potential genetic structuring of sockeye salmon in the Cedar River may be more temporally dependent than spatially dependent. A preliminary genetic study based on a single spawn year (1997-98) indicated a positive correlation ($r = 0.475$; $P = 0.053$) between differences in spawn dates and genetic distances for groups of sockeye salmon spawning on different dates (Bentzen and Spies 2000). That study needs to be repeated to determine whether the observed temporal genetic variation is a stable attribute of the population structure or simply reflects a stochastic year class or brood year effect (see Research Needs).

In practice, all fish spawning upstream of the weir in the Cedar River will initially be treated spatially as a single population because we will not know the location within the river where adult fish retained for broodstock would have spawned. As noted previously, we are recommending that the weir be placed at the lowest possible downstream point in the Cedar River. Such a location will allow monitoring and evaluation of the entire run both spatially and temporally, including potential clarification of the relationships among return timing, spawn timing, and spawning location within the Cedar River. The target population for hatchery enhancement will thus be all adult spawners in the Cedar River upstream of the weir with potential temporal genetic structuring being maintained by natural variation in spawn timing. Potential spatial genetic structuring will similarly be maintained if it is highly correlated with spawn timing. This working model implicitly assumes that retention of adult fish for broodstock will not significantly affect the maturation schedules and spawn date of those broodstock fish. Potential genetic structuring related to return timing to the weir can also be maintained by appropriately marking or tagging all adult fish retained for broodstock (see Monitoring and Evaluation section).

Recommendation 7. Adult fish retained for hatchery broodstock must represent a random sample of the target population each year.

To achieve the conservation goals of the Cedar River hatchery, the phenotypic distributions (mean, variance, range) of fitness-related traits (e.g. time of return, spawn date, adult size, age class structure of spawners, etc.) must be equal for fish retained for broodstock and for fish allowed to spawn naturally in the Cedar River. This will require that an equal proportion of adults arriving each week at the weir be retained for broodstock. If run timing follows a normal (or pseudo-normal) distribution, the actual numbers of adults retained for broodstock will be low at the beginning and ends of the run but high in the middle. Thus, the vast majority of the fish retained for broodstock will be trapped during the middle half of the run (approx. September 15 – November 30). Fish retained for broodstock must be selected randomly among all fish trapped regardless of origin (hatchery or wild), size, age, or condition. The only exception to this general rule might be obviously diseased fish, which could pose a significant disease risk if they were retained for broodstock.

Recommendation 8. The number of adult fish retained for broodstock each year should be based on the predicted total escapement to the Cedar River (Table 1) and shall not exceed the number of adult fish allowed to spawn naturally (i.e. 50% of the total number of adult fish) except when emergency conservation measures warrant retention of all adult fish for hatchery spawning.

The potential exists for the recruit-per-spawner ratio, or adult replacement rate, of adults spawning in the hatchery to be at least ten times (10x) the R/S ratio of adults spawning naturally in the Cedar River (Table 2). Consequently, as with all hatchery programs, hatchery-origin fish could eventually dominate the total number of returning adult fish and eventually replace natural spawners if (a) total escapement goals are not achieved or (b) fry-to-adult survivals for naturally-produced fish are exceptionally low due to stochastic environmental effects or other factors. The recommendation presented here emphasizes the important role of natural selection in the Cedar River for maintaining the genetic integrity and wild fish characteristics of the population as a whole. On the other hand, in the event of a catastrophic loss of a particular brood year due to stochastic environmental effects in the Cedar River, it may be desirable to spawn all adults in the hatchery if total returns one generation (four years) later are less than the spawner capacity (10,940 females or approximately 20,000 fish) of the hatchery. These recommendations will help ensure the genetic integration of natural and hatchery fish, as well as focusing on the need to truly understand the population dynamics and recruit-per-spawner ratios for adults spawning naturally in the Cedar River and artificially in the hatchery.

Recommendation 9. At least 10% of the broodstock each year shall be comprised of natural-origin (wild) adults.

The principal goal of this recommendation is to maintain genetic continuity between the hatchery and wild components of the population and the two respective environments. Because fish retained for broodstock will be selected randomly (in a stratified manner) from all adults returning to the Cedar River, the recommendation described here will be achieved *if* (a) total escapements to the Cedar River exceed 100,000 fish and (b) fry-to-adult survivals of hatchery-produced fish are less than or equal to those of naturally-produced fry (Tables 1 and 2). In general, we would not expect those fry-to-adult survivals for hatchery-produced fish to be greater than those for naturally-produced fish; the principal survival advantage of the hatchery is at the egg-to-fry stage. Because hatchery fish will be released as unfed fry (but with thermally-marked otoliths), the hatchery or wild identity of adults retained for broodstock cannot be made until after the fish are killed and spawned. Consequently, the proportion of wild and natural origin adults used for broodstock each year (based on otoliths) will be a critical monitoring and evaluation tool to assess the success or failure of the hatchery program. Indeed, failure to achieve the 10% recommendation in consecutive brood years would be one indication that the hatchery program was largely replacing natural reproduction and thus failing to meet one of its primary objectives. On the other hand, at least 25% of the adults retained for broodstock each year would be of natural origin if the hatchery program was fulfilling its objectives (Table 1). *Recommendations 8 and 9* thus place upper and lower constraints on the broodstock composition. Failure to meet these recommendations would thus indicate (a) a virtual collapse of the Cedar River (and/or Lake Washington) to support natural reproduction or (b) a complete failure of the hatchery program to achieve its objectives with respect to sustaining naturally-spawning populations in the Cedar River. The principal difference between these latter two alternatives is whether the collapse of natural reproduction in the Cedar River was due to the direct and indirect effects of the hatchery program or due to extrinsic environmental factors (urban development, channelization, pollution, etc.) independent of the hatchery program.

Recommendation 10. The number of males retained for spawning at the Cedar River hatchery should equal the number of females retained to maximize the effective population size of the hatchery broodstock. However, given the large number of females that will be spawned at the Cedar River hatchery (up to 10,000 females), it is genetically acceptable to retain a maximum of 5,000 males if those males are retained in a stratified manner identical to the manner in which females are retained (i.e. do not collect 5,000 males from the first half of the run and then stop collecting males).

The need to maximize genetic effective sizes of natural and artificially propagated populations has been the subject of intense theoretical study (Franklin 1980; Soule 1980; Lande 1988, 1995; Ryman and Laikre 1991; Ryman et al. 1995). From the standpoint of transmitting genetic variation (i.e. alleles) between parental and progeny generations and maintaining a constant variance for quasi-neutral genetic variation (i.e. that can serve as a genetic reservoir for future adaptations), an effective population size of 5,000 adults per generation is nearly as large as a population of infinite size (Lande 1995). Hence, based on genetic arguments, it is not necessary to spawn more than 5,000 males per year to maximize the effective number of breeders per year (see Table 1). In this latter situation, each male would be spawned with two females following the existing procedures at the

Landsburg facility (see *Recommendation 11* below). An equal number of males and females should be spawned if less than 5,000 females are retained.

Recommendation 11. Male and female sockeye salmon <u>retained for broodstock</u> shall be mated and spawned in a manner that allows each adult fish to potentially make equal genetic contributions to the progeny generation.

Several studies have demonstrated highly variable genetic contributions by male parents to progeny when eggs and milts from several males and females are mixed simultaneously (Gharrett and Shirley 1985, Withler 1988, Withler and Beacham 1994). Under such conditions, a high amount of sperm competition occurs such that one male may fertilize a large majority of the eggs while the other males make only minor genetic contributions. Strict pairwise mating between males and females gives each male an equal opportunity to make a genetic contribution to the progeny generation. Existing spawning protocols at the Landsburg facility, including the use of a second "back-up" male two minutes after the initial mixing of eggs and milt from the first male, are consistent with this recommendation described here.

It is understood that random mating and pairwise spawning, as recommended in the hatchery spawning protocols, does not occur in the wild. Assortative mating, controlled by the female selection of the mating male, and intense competition among males for dominance will skew the mate selection in a non-random manner under natural conditions. However, the goal of the hatchery program is not to try and simulate natural reproduction by "second-guessing" natural selection. On the

contrary, the goal of the hatchery program is for the genetic constitution of the released fry - in terms of their composite gene frequencies - to be identical to the genetic constitution of their parents that were randomly selected for broodstock. This goal requires minimizing - and hopefully eliminating as much as possible - artificial and natural selection in the hatchery environment (see *Recommendation 12*). Ensuring equal genetic contribution by the spawned parents to the progeny generation not only helps achieve this latter objective, it also maximizes effective population sizes. In this context, the large number of spawners to be used for broodstock at the Cedar River hatchery

Recommendation 12. The hatchery system should be designed and operated in a manner that prevents deliberate or inadvertent artificial selection with the goal that the genetic composition of progeny fish released from the hatchery is identical to the genetic composition of their parents retained for broodstock each year.

The incubation, hatching, and release environments of fertilized eggs and their resulting fry in the hatchery must be uniformly applied to all progeny to ensure that no differential selection among families occurs in the hatchery. Although some egg losses representing one or more single pair matings are inevitable, this should occur in a stochastic, non-systematic manner. Because progeny fish will be allowed to emerge volitionally and outmigrate as unfed fry, the potential for the hatchery environment to impose strong natural selection on those fish, either in the hatchery or after their release, is considered negligible. *Recommendations 8 and 9* should ensure that relaxed selection for spawning behavior and fertilization success in the hatchery environment do not allow random accumulation of alleles that are selectively neutral in the hatchery environment but deleterious under natural conditions. However, gene flow thresholds necessary to prevent this latter sort of genetic change in salmon populations has not been thoroughly investigated, and the hypothesis that such genetic loads accumulate in populations under conditions of relaxed selection is largely theoretical.

C. Health:

While several important diseases of salmonid fish are capable of causing losses among sockeye salmon reared in captivity, the design and operation of the Cedar River incubation facility should be such that these are expected to be manageable, providing few opportunities for disease to affect the hatchery fish before release. In addition to preventing or minimizing disease in the hatchery, these recommendations will also insure that the hatchery does not serve to introduce new diseases to fish in the Lake Washington system or to amplify the level of diseases already endemic. The following recommendations will insure that the risk from infectious disease is minimized.

Recommendation 13. Hatchery design must provide for control of infectious and non-infectious diseases.

Experience at numerous sockeye salmon hatcheries in Alaska and in British Columbia, Canada, shows that specific hatchery design elements are critical to preventing losses from infectious diseases. These include: use of a pathogen-free water supply with adequate flow and appropriate water quality (temperature, pH, DO); use of low density incubation and rearing; and use of isolated units containing a minimal number of eggs or fry that will contain disease outbreaks to small groups of fish. Successful sockeye salmon hatchery designs, already in place in Alaska (ADF&G 1994), in British Columbia, Canada, and at the interim facility on the Cedar River should be incorporated into the final hatchery design.

Recommendation 14. Standard operating procedures must be in place at the hatchery to limit transmission of infectious agents and to control outbreaks of disease.

Coupled with optimal hatchery design and use of a pathogen-free water supply, standard operating procedures at the hatchery must be scrupulously followed to insure that sockeye salmon eggs and fry are not exposed to infectious agents via contaminated eggs, equipment, or personnel. These procedures should include the routine iodophor treatment of eggs for elimination of IHNV and other egg-associated pathogens, strict sanitation protocols for equipment and staff, and guidelines to be followed in the event of a disease outbreak. Again, successful sockeye salmon rearing approaches, already in place in Alaska, in British Columbia, Canada, and at the interim facility on the Cedar River should be incorporated into these standard operating procedures.

D. Ecology:

Supplementation of sockeye salmon must be managed within the context of the structure and function of the Lake Washington ecosystem. Food web dynamics will largely dictate the growth and survival performance of sockeye salmon from the time of their release as fry until the smolts migrate to saltwater after residence in the Lake. Environmental conditions (magnitude of flooding, nutrient loading, seasonal temperature patterns, etc.) will also influence biological interactions by altering the timing and availability of food, encounter rates with predators, and access to temperatures that promote optimum growth. Hatchery fry add to the population of zooplankton consumers in the lake, and they could potentially alter the behavior, distribution, and feeding patterns of predators. Therefore, hatchery management should consider how the quality (e.g., size, genetic similarity to wild sockeye), quantity, and migration timing might affect wild sockeye and other species in the Lake Washington drainage. Although the lake's food supply appears more than adequate to maintain sockeye production in the system, the hatchery should not disrupt the structural and functional integrity of the natural food web dynamics in the Lake. The ecological considerations for sockeye enhancement, therefore, must be evaluated from a community- or ecosystem-level perspective.

Recommendation 15. Carrying capacity, or the seasonal food supply for juvenile sockeye salmon and other zooplankton consumers, should not be exceeded.

The food supply that dictates the carrying capacity of Lake Washington will vary from year to year, and is related to the seasonal environmental conditions of the lake, and to the zooplankton consumption by *Neomysis mercedis* and planktivorous fishes. These factors determine the seasonal carrying capacity for both wild and hatchery sockeye salmon and other planktivores. This was most recently demonstrated by bioenergetic modeling simulations of monthly consumption demand by the entire planktivorous fish community (Beauchamp 1996) and *Neomysis* (Beauchamp, unpublished data). These data were compared with monthly *Daphnia* biomass and production to examine the seasonal food supply and consumer demand relationships in Lake Washington. Two years were chosen to represent:

a) a period of high planktivore demand (April 1989-March 1990) when a strong even-year class of age-1 smelt coincided with a strong year class of juvenile sockeye salmon,
b) low planktivore demand (April 1990-March 1991) when a weak year class of age-1 smelt coincided with a weak year class of juvenile sockeye salmon.

The simulations assumed that *Daphnia* was the only prey species utilized by juvenile sockeye salmon throughout their lake-rearing period, and thus provided a conservative assessment of food supply. Prior to the establishment of *Daphnia* in the lake, juvenile sockeye salmon and other species historically consumed copepods (*Epischura nevadensis*, *Diaptomus ashlandi*, *Cyclops*), other cladocerans (*Diaphanosoma*), and chironomids. These prey are still available in moderate to high densities and represent an alternative (although less desirable) forage base, particularly when *Daphnia* populations naturally decline in late fall and winter. The modeling simulations indicated that consumption by fish and *Neomysis* exceeded the supply of *Daphnia* during January-March in 1990 and 1991 which corresponds with the first half of the fry migration period into the lake.

Consumption by planktivorous fishes and *Neomysis mercedis* removed a relatively small fraction of the lake-wide biomass of edible-sized *Daphnia* during the April-November growing seasons in 1989 and 1990; however, sockeye salmon only foraged at intermediate depths (10-20 m) where zooplankton densities are significantly lower than at shallower depths during summer stratification. Because of the deeper depth distribution of sockeye, the available *Daphnia* supply for sockeye could be more limited than for other planktivores unless zooplankton from the upper waters commonly circulate down across the thermocline to replenish the zone where sockeye feed.

A major remaining uncertainty is the reliability of the population estimate for *Neomysis*, which was derived from seasonal distribution and density reported by Chigbu et al. (1998). *Neomysis* were sampled with a net (0.2 mm mesh bongo net) that may have significantly underestimated the true density of mysids, and severely underestimated the density of larger mysids due to their higher net-avoidance rates. These mysid estimates could conceivably be 10-times too low. Consequently, the year-round estimate of mysid consumption should be considered a very minimal estimate of their potential consumption demand on *Daphnia* until the earlier estimates of mysid density can be compared and calibrated to density estimates using more appropriate sampling gear (e.g., a 1-m diameter zooplankton net with 1-mm mesh).

The addition of up to 34 million hatchery fry plus natural fry production of 5-30 million could stress the seasonal prey resource base for juvenile sockeye and other planktivores. Fry that enter the lake before April would need to rely on alternative prey until *Daphnia* production accelerates. In fact, more recent data (Martz et al. 1996, A. Litt, unpublished) indicate that juvenile sockeye salmon include other prey in their diet during winter and early spring, and some fry inhabit and forage in littoral areas initially before migrating offshore. The availability and use of habitat and prey resources by sockeye salmon fry during winter and early spring is still a major uncertainty that requires resolution before the potential success or impacts of sockeye hatchery operations can be evaluated.

Recommendation 16. Enhanced sockeye production should not negatively disrupt predator-prey dynamics in the Lake Washington system.

Predator-prey interactions among predators, juvenile sockeye salmon, and other potential prey fishes must be understood to determine whether more fry production will produce a reasonable increase in high quality smolts, be lost to predation, or alter the predator-prey dynamics to the detriment of other desirable species in the drainage. How much loss can be expected from instream predation by sculpin, cutthroat trout, and other predators on fry migrating to the lake? When wild steelhead were more abundant in the mid 1980s, wild steelhead smolts consumed an estimated 6.8 million sockeye fry in 1985, and predation was concentrated from February through mid-April (Beauchamp 1995). As wild steelhead are restored, more instream predation losses can be expected, and should be factored into the hatchery and basin-wide management programs. More recently, Tabor et al. (1998) reported measurable and consistent levels of predation on migrant sockeye fry, primarily by sculpin and cutthroat trout from March through May or June. These observations should be quantified into estimates of population-level predation rates. If significant, what factors (flow, migration timing over diel and seasonal time scales, artificial lighting, stream habitat characteristics) affect these predation rates?

Tabor et al. (1998) and the Muckleshoot Tribe (unpublished data) indicate that sculpin predation on juvenile sockeye continues during the lake-rearing phase for sockeye; predation involves all sizes of juvenile sockeye over a range of depths, and potentially persists throughout the year. What seasons, locations, and size ranges of sculpin feed on what size range of sockeye? Since sculpin represent approximately 80% of the fish biomass in the lake (Eggers et al. 1978), their predation potential is immense. Estimates of their actual predation rates are unknown, and highlights the importance of research and monitoring to resolve this question and thus the impact of sculpins on juvenile sockeye.

Cutthroat trout and northern pikeminnow eat significant amounts of juvenile sockeye salmon throughout their freshwater rearing phase as well, with cutthroat as the most important of all limnetic predators on juvenile sockeye salmon (Beauchamp 1994). The cutthroat trout population has expanded steadily from the 1970s through the 1990s. It is unknown how these predators will respond to increased densities, or more stable high production, of sockeye salmon fry resulting from the enhancement program. Production of more sockeye fry could potentially result in stimulating the predator population rather than markedly increasing sockeye smolt production, or it could result in initiation of cyclic dominance in the Lake Washington sockeye system.

Recommendation 17. Enhanced sockeye production should not disrupt the natural population dynamics among other O. nerka populations or resident fish species in the Lake Washington system.

Effects of the supplemented Cedar River sockeye on other sockeye and kokanee populations is an unknown that needs to be carefully followed. Natural trends in the ecological relationship among *O. nerka* populations in the growing presence of one population is well studied in Alaska and British Columbia. These interactions are long-term, but none-the-less need to be assessed in terms of genetic interactions and population strengths within the Lake Washington system. Other sockeye could be advantaged by abundant Cedar River sockeye, and encouraged to follow the same abundance trends as the latter. However, the enhancement of sockeye is expected to have negative impact on kokanee abundance in Lake Washington, as discussed above, and will perhaps more strongly reinforce genetic similarity between sockeye and kokanee from the expected contribution of resident forms stimulated by increased sockeye production. No affects of the Cedar River sockeye hatchery production are anticipated on the Lake Sammamish kokanee population.

Then there is the issue of smelt population stability, and the role that smelt appear to play in buffering predation on sockeye and controlling the density of *Neomysis mercedis*. If increased sockeye production results in the concomitant increase in predation on smelt or increased competition with the smelt food supply, the *Neomysis* population could expand and thwart the benefits of increased sockeye production. Rainbow trout are the major predator of smelt in the lake, and the rainbow stocking program during the 1980s is believed to have decreased the smelt population size during that period. Similarly, the dredging of the lower Cedar River, which is one if the primary spawning areas for the smelt population, is another factor that may already limit the potential of the smelt population in the lake. No other freshwater population of smelt has been so successful as in Lake Washington, and few such populations are known to exist. Therefore, the influence of the sockeye hatchery program on the smelt population needs to be included in any assessment of population interaction in the system with enhancement of Cedar River sockeye. These interactions may have the most important implications on the ultimate form of the sockeye enhancement program in Lake Washington.

Section IV. Monitoring and Evaluation:

During the lifetime of the project, it will be important to monitor hatchery operations and water quality, stock genetic diversity, juvenile sockeye performance, fish health, and ecosystem response associated with the hatchery program at the hatchery facilities, Cedar River, and Lake Washington and its associated watershed. The monitoring effort should include activities listed in the following areas.

Hatchery Production:

1. Dissolved oxygen determinations: Determinations of dissolved oxygen need to be made at predetermined monitoring stations at least weekly to confirm that incubating embryos and alevins are within the tolerance standards established for incubation.

2. Flow determinations: Daily measurements of incubator flows need to be taken to assure that irrigation rates through incubators are being maintained.

3. Monitoring fry developmental index at emergence: It will be necessary to assess the developmental index (*kD*) of fry from the hatchery and wild components to determine similarity in condition at emergence and distribution from the hatchery. This will assure that incubation substrate and environmental conditions during the process of incubation and emergence are within the standards considered normal for natural incubation.

4. Monitoring fry emergence timing: A routine schedule should be followed in an assessment of emergence timing for each temporal segment of the hatchery population with the timing of the coincidental temporal segments targeted in the natural spawning population. This will assure that incubation temperatures are performing as planned in coordinating emergence timing between hatchery and naturally spawned population segments.

5. Adult holding performance: Broodstock held in the holding facilities will need to be monitored for ripening performance, arrival date vs. spawning date, pre-spawning mortality, and physical condition over the holding period. These data will be important is assessing effectiveness of the holding/spawning routine and in determining changes that can be made in the physical facility that will improve pre-spawning conditions.

B. Genetics and Population Dynamics:

1. Hatchery and wild broodstock: The proportion of the broodstock composed of hatchery-origin and wild-origin adults needs to be estimated each year. This will require analysis of a random sample of otoliths from fish spawned weekly at the hatchery.

2. Hatchery survival and recruit ratios: Fry-to-adult survival rates and R/S ratios need to be estimated for each brood year of fish released from the Cedar River hatchery. This will require (a) estimating the total return of adults to the Lake Washington watershed and (b) determining the proportion of the total adult return that is comprised of Cedar River hatchery fish (via otolith marks).

3. Natural survival and recruit ratios: Fry-to-adult survival rates and R/S ratios for fish spawning naturally in the Cedar River should be followed. A negative correlation in the estimated values of these parameters with the number of fry released from the hatchery would imply that the program was negatively affecting the population dynamics of the naturally spawning population in the Cedar River and/or Lake Washington.

4. Molecular genetic (DNA) monitoring of the hatchery population: Sampling of adult spawners and emerging progeny for the hatchery and natural spawners should be conducted annually for the first four years and repeated 12 years later to evaluate potential genetic variation among brood years and generations, and to assess potential changes between fry and adult life history stages within brood years. These assessments would be conducted as part of tasks 1 and 2 under Research Needs.

5. Temporal and spatial run segments: Monitoring of the spatial:temporal relationship between arrival, spawning time, and location will need to be established to provide and refine the spawner segment model on which fry release strategy will be based. This will entail a tagging program at the weir site to give the temporal segments of the run physical identity to relate with spawning time and distribution.

6. Straying from the Cedar River sockeye population: Genetic monitoring of straying and potential interbreeding by Cedar River Hatchery fish with other Lake Washington populations of sockeye salmon and kokanee (see also task 8 under Ecology M&E). The presence of Cedar River adults/carcasses in other tributaries of the Lake Washington watershed, particularly Bear Creek, should be followed by DNA analyses of outmigrating fry to assess the extent to which Cedar River fish may have spawned in those tributaries. This task will depend upon the establishment of adequate genetic baselines for the principal sockeye salmon and kokanee populations in the watershed.

7. Spawning efficiency: Cedar River spawning ground surveys should assess the percentage of sockeye carcasses that have spawned out from the early, mid-point, and later part of the run. The long-term trend in the population should be followed to monitor potential effects of hatchery influence on spawning efficiency, but otoliths from the carcasses should also be taken to compare spawning efficiency of hatchery and wild fish. If trends appear in reduced spawning efficiency, research on the cause should follow.

C. Health:

1. Annual fish health inspections at the hatchery: These should include collection of statistically-based samples from returning adults used as broodstock and all lots of released fry. Tissues and/or reproductive fluids should be assayed for viral, bacterial, protozoan and fungal pathogens. The prevalence and titers of infectious agents in both adults and fry need to be monitored carefully over time.

2. Annual monitoring of free-ranging fish in Cedar River: This should include collection of statistically-based samples of both salmonid and non-salmonid species from selected regions of the Cedar River both above and below the hatchery. Samples should focus principally on spawning salmonids if prevalent in adequate numbers. Otherwise, resident species or sentinel fish could be used. Tissues and reproductive fluids should be assayed for viral, bacterial, protozoan and fungal pathogens with special emphasis on identifying previously unknown or newly introduced pathogens. The prevalence and titers of infectious agents in these free-raging species need to be monitored carefully over time, especially in fish above the hatchery.

3. Regular monitoring of free-ranging fish in Lake Washington and its tributaries: At 1-3 year intervals, statistically-based samples should be collected from salmonid and non-salmonid species at selected locations in Lake Washington and selected tributaries. Samples should focus principally on spawning salmonids if prevalent in adequate numbers. Otherwise, resident species or sentinel fish could be used. Tissues and reproductive fluids should be assayed for viral, bacterial, protozoan and fungal pathogens with special emphasis on identifying previously unknown or newly introduced pathogens. The prevalence and titers of infectious agents in these free-raging species need to be monitored carefully over time.

D. Ecology:

1. Limnological monitoring: Continue and expand limnological monitoring program (vertical temperature, oxygen, light, chlorophyll, and turbidity profiles are provided by King County's 3 Limno-buoys).

2. Assessment of food supply: Zooplankton surveys every 14 days during April-October and monthly November-March. (0-10m, 10-20m, >20m sample intervals; expand coverage to at least 3 sampling stations (North, Madison Park [central], and South). Include egg counts for *Daphnia* and size structure for *Daphnia* spp and copepods. Seasonal density, size structure, and vital rates for the primary zooplankters provide an important early indicator of ecological problems.

3. Seasonal Mysid shrimp sampling: Institute seasonal *Neomysis* sampling (every 3-6 months) to monitor trends in mysid abundance as it relates to their response to changes in predatory control by smelt and the potential for predatory control by mysids on *Daphnia*. Night sampling with vertical net (1-m diameter, 1-mm mesh) hauls stratified by region and bottom depth. *Neomysis* reproduce in spring and fall, thus their abundance can increase more rapidly to changes in predation mortality than fish. Consequently, a seasonal *Neomysis* assessment program is advised.

4. Otolith marking: The thermal otolith marking of all hatchery fry (by emrgence time and release location) and the sockeye fry trapping program at Cedar River and Bear Creek should become a permanent element of the research and monitoring program.

- This program provides essential data on the timing and abundance of fry entering the lake and the proportional contribution of hatchery and naturally-spawned fry through the outmigration season and among years.
- These programs also enable estimates of egg-to-fry survival and migrant survival as functions of stream flow, nightly abundance of migrating fry, migration distance, etc.
- The fry trapping program enables sources of mortality during incubation and fry migration in the streams to be separated from in-lake sources of mortality. This is extremely important, because the potential remedies for instream mortality would be radically different from those targeting in-lake mortality.

5. Sockeye lake surveys: Midwater trawls and hydroacoustic surveys should be conducted at least twice a year (spring sockeye presmolt survey, fall smelt-sockeye survey are essential), preferably 3-4 surveys per year. This provides information on abundance, distribution, growth and food habits near the end of the growing season, and allow an evaluation and comparison of sockeye growth across a range of abundance levels of sockeye and competitors among years. These surveys would provide essential assessments of sockeye abundance and help isolate periods of heavy mortality after fry emigration. When combined with the otolith marking program for hatchery sockeye, these seasonal inlake samples enable evaluations of the relative performance and overall contribution of hatchery versus naturally-spawned sockeye. Periods of differential survival or growth could be identified, isolated and more easily attributed to seasonal bottlenecks in predation, food supply-competition, environmental conditions, etc. Night vertical hauls at various locations and depths around the lake should be undertaken every 3 to 6 months to quantify the Mysid shrimp population trends .

6. Juvenile sockeye abundance and growth: Integrate fry and smolt sampling at the Chittenden Locks into the fry trapping and trawl-hydroacoustic assessments of sockeye and abundance and growth. Although not currently practiced, a final estimate of smolt abundance may be possible by developing new trapping and assessment procedures at the locks. Sockeye exhibit significant growth and suffer additional mortality between the

presmolt survey in the lake during late March (midwater trawl and hydroacoustics) and their peak outmigration through the locks in June.

7. Predation monitoring: Some modest level of routine predator sampling should be developed in the future, based on the results of an initially more intensive research effort listed in the Research section below.

8. Spawner surveys: Spawner and carcass surveys should be conducted every 1-2 weeks throughout the spawning season in the Cedar River, Bear Creek, and less frequently at other potentially important spawning areas during the peak of the spawning season.

- Spawner counts and otolith samples from carcasses should be recorded by date and river mile.
- Otoliths should be examined for thermal marks from representative samples of carcasses (e.g., a fixed percentage of carcasses [sample every n*th* carcass] encountered spatially and throughout the spawning run). These data will provide information on the proportional contribution of hatchery-spawned progeny to the pool of naturally-spawning sockeye in each brood year, and will identify segments of the hatchery-spawned progeny (uniquely marked by emergence timing and release location) that contribute disproportionately to the run.

Section V. Research needs:

To provide the most effective hatchery program under the mandate of the Landsburg Mitigation Agreement, the panel also identifies topical research that will provide basic insight on the influence of the hatchery program on the lake ecosystem. The primary effort should be given to the following research topics:

A. Hatchery Production:

1. It is considered most compatible with the wild-like theme of the program to mimic size and timing of the naturally produced fry. Therefore, before considering the possibility of any rearing prior to release of sockeye juveniles, the need and expected benefits to the wild-like theme should be demonstrated in research programs aimed at assessing the contribution of temporal segments within the combined wild and hatchery populations.

2. In line with the research needs to improve hatchery performance, part of the hatchery program will be to research techniques that may assist in overall return production survival of hatchery fish. Research on release strategy (i.e. pulse release, fed fry releases vs. non-fed fry releases, fingerling releases, smolt releases) should be considered as part of the general hatchery approach to refine hatchery technology as options that could be applied to Cedar River sockeye.

3. Juvenile imprinting and adult return locations of the hatchery released fish is another element of the research plan that should be undertaken to determine the distribution of hatchery fish when released at sites downstream from the hatchery. This will require spawning ground surveys of carcasses for otolith marks that can relate hatchery carcass recovery sites to fry release locations.

B. Genetics and Population Dynamics:

1. To provide the database on *O. nerka* genetics in the Lake Washington system, genetic profiles of the *O. nerka* populations will need to be established. Therefore, the preliminary study of Bentzen and Spies (2000) should be repeated for three additional years, beginning with collection of fin clips from adults returning in 2001. The positive correlation between differences in spawn date and genetic distances (ibid.) could simply reflect demographic structuring within a single brood year and not necessarily a stable attribute of the population structure. In other words, genetic distances among groups of fish spawning in different years within particular temporal segments of the run (e.g. early spawners) could be as great (or greater) as the genetic distances among different spawning groups (e.g. early spawners versus late spawners) within a single spawning season. Additional research is needed to distinguish the two sources of temporal genetic variation and determine the biological significance of the temporal genetic variation reported by Bentzen and Spies (2000) in their preliminary study. The issue of a potential

correlation between fitness of progeny and temporally-based genetic adaptations over the run timing of the Cedar River sockeye population will need to be understood to assess potential temporal changes in population structure as the integrated hatchery-wild population reaches equilibrium with the carrying capacity of Lake Washington. Looking at the genetic profiles of the temporal segments of the population - and segregating the diversity over the temporal timeframe of return, spawning, and emergence patterns - will establish the database on which subsequent analyses can be performed. Although such data will be an assemblage of the diversity based on neutral alleles, it will serve to assist in assessing the presence of and diversity around various segments of the spawning population.

2. The spatial distribution of natural spawners in the Cedar River watershed and the potential correlations between arrival time at the weir and spawning location within the watershed (see also task 8 under Ecology M&E) need to be determined. A random sample of adults arriving at the weir each week should be trapped, tagged with color-coded disk tags, and then released to spawn naturally in the watershed. Spawner and carcass surveys should then be conducted to determine the spawning locations of adults in the watershed relative to their arrival time at the weir. Small fin clips should be obtained from each adult fish released to spawn naturally for genetic (DNA) studies of population structure. This work should be conducted for four consecutive years.

3. Baseline gene frequency data with nuclear DNA markers also should be collected for the principal populations of sockeye salmon and kokanee in the Lake Washington watershed, including natural spawners in the Cedar River (see Task 2 above). Samples of outmigrant fry or carcasses (N=50-100 individuals) should be obtained for four consecutive years from each population. These genetic profiles and baseline databases will be used to monitor potential population genetic changes in the Cedar River and other areas of the Lake Washington watershed from straying (e.g. potential loss of genetic diversity among populations). Such research will also establish more concisely the relationships of the different geographical populations of *O. nerka* in the Lake Washington system.

4. The potential success of the Cedar River hatchery program in terms of its specific objectives depends on the assumed ability of hatchery-origin adults to spawn naturally and reproduce successfully in the Cedar River. While reduced spawning ability of hatchery fish is unlikely, none-the-less this assumption should be tested explicitly via controlled spawning studies if reduced efficiency is consistently demonstrated in spawning ground surveys (see monitoring [#7] above). Research on this would include observations (in river or prepared study sites) that could be related to genetic changes observed in the wild and or hatchery populations.

C. Health:

1. Determine the species of fish or invertebrates that can serve as vectors or reservoirs for important fish pathogens affecting hatchery fish as well as other fish in the Lake Washington system. How are fish pathogens maintained and transmitted within the watershed.

2. Determine the strains, serotypes or genotypes of pathogens isolated from the monitoring or research efforts. Do these change over time? Perform challenge studies with sockeye fry or other species of interest to look for changes in virulence. Archive isolates.

3. Determine the nature of the latent carrier state (if any) in sockeye salmon or in other species that may serve as reservoirs of IHNV. Are latent infections in returning adult sockeye salmon reactivated at spawning or are the returning adult fish reinfected as they enter Lake Washington or the Cedar River? Is the infection spread by waterborne transmission or are vectors (e.g. leeches) involved?

4. Determine the efficacy of passive immunization or vaccination of returning adult sockeye if fish must be held for some time before spawning. This will reduce level of IHNV or other pathogens in individual adult fish, reduce fish-to-fish transmission, reduce level of infectious agents released from the adult holding facility, and lower chances that pathogens on eggs will escape iodophor treatment to affect fry.

D. Ecology:

1. Does a mismatch exist between the timing and distribution of sockeye fry entering the lake and the spatial distribution of the zooplankton food supply? If fry remain concentrated in the southern end of the lake, the local food supply could be depleted, especially since *Daphnia* densities do not increase until April or May. If fry disperse throughout the lake, then localized prey depletions would be minimized. The diet composition and spatial distribution of fry during winter and early spring are not well understood, and could represent a significant period of mortality or reduced growth. Therefore, a food habits/food supply study should be conducted during the early life history of sockeye fry in the lake. The initial focus should be on the southern region of the lake during the first year (study underway in 2001). If these results suggest severe trophic bottlenecks here, then the study should be extended to the northern and central regions of the lake. Several elements of study need to be undertaken.

    - Examine distribution and habitat use of fry Feb-May in deeper shore slope regions (small bottom trawls), littoral areas (beach seines), midwater (Kvichak trawl) and near surface (2-boat surface trawls). Sampling frequency monthly from mid February to mid May. Spatial coverage: intensively sample selected sites south of I-90 bridge, but also sample an additional 5-10 sites from north of I-90 to Kenmore to examine the timing and magnitude of fry dispersal
    - through the lake. Link net sampling with side- and down-looking hydroacoustics to enhance effectiveness of net sampling and analysis of temporal-spatial fry distribution and dispersal.

- Counts, lengths, and weights of all species will be recorded. Stomach samples will be preserved from a subsample of all species.
- Zooplankton will be sampled from open water and slope zone sites at subset of the fish sampling sites south of I-90 during February-May. Some day-night comparisons of species composition, density, and vertical distribution.
- Examination of food habits and prey supply for sockeye fry and potential competitors during the early lake residence of sockeye fry. Fish stomach analysis and zooplankton processing for samples collected from the early sockeye fry feeding and food supply study funded by WDFW (above), fish samples from the presmolt and fall fish surveys, and for the supplemental routine zooplankton samples from northern and southern stations.

2. Abundance estimates for major predators and competitors, especially age-2 and older cutthroat trout, northern pikeminnow > 300 mm fork length, prickly sculpin >50 mm total length, age-1 and older yellow perch, smallmouth and largemouth bass >100 mm fork length. Estimates of juvenile sockeye, longfin smelt, and threespine sticklebacks can be obtained using hydroacoustics and midwater trawl surveys. The lack of reliable abundance estimates for the larger-bodied species has handicapped our ability to truly evaluate the impact of various predators and competitors on sockeye production and on the general community dynamics in the lake. Because of species-specific differences in size, behavior, and distribution, different methods will be required to estimate abundance for different groups of species. Some species can be targeted for direct assessment (e.g., mark-recapture estimation or area-swept methods) whereas other populations may be estimated indirectly by comparing their relative catch per unit effort to that for directly-estimated species in situations where catch efficiencies can reasonably be assumed to be similar for a common sampling method. Other prominent fishes in the lake (i.e., largescale suckers, peamouth) could also be assessed indirectly by the process described above.

3. In-river observations of sculpin predation (Tabor et al. 1998) should be supplemented and quantified into estimates of population-level predation rates. If significant, what factors (flow, fry abundance, river migration distance, migration timing over diel and seasonal time scales, artificial lighting, stream habitat characteristics) affect these predation rates (Seiler and Kishimoto 1997, Tabor et al. 1998)?

4. How will cutthroat trout and northern pikeminnow respond to increased densities, or more stable high production of sockeye salmon fry due to the enhancement program? How will cyclic abundance patterns of smelt, an important alternate prey source for these predators, interact with changes in sockeye abundance? By producing more sockeye fry, will we realize more sockeye smolt production or simply feed the predators? Where are we on the functional response curve of the major predators?

5. Research on smelt population stability, and the role of smelt in buffering predation and controlling *Neomysis mercedis* is a subject needing attention. How have smelt responded to the decline of their major predator (rainbow trout, due to termination of the stocking program) and dredging of their spawning grounds in the lower Cedar River?

The status of the smelt population can be assessed effectively by annual hydroacoustic-midwater trawl surveys in autumn and/or summer. The preponderance of diet data from predators has unfortunately occurred during years when strong year classes of smelt were available (Beauchamp 1990 & 1994, Beauchamp et al. 1992, Nowack 2000, Brocksmith 1999). Some predation data have also been presented for years when weak year classes of smelt were present, but definitive analyses of predator responses and impacts have been hampered by strong diet data from consecutive strong-weak year class cycles. The Muckleshoot Tribe may have the data to satisfy these unknowns (Eric Warner, personal communication), but until analyses and reports have been completed and reviewed, this important information need must be considered a critical unknown, and may require additional research, particularly on the seasonal diet of offshore predators.

6. In-lake predation by sculpin also needs attention. At what seasons, locations, and size ranges do sculpin feed on size classes of sockeye? Since sculpin represent approximately 80% of the fish biomass in the lake, their predation potential is immense. Estimates of their actual predation rates are an important unknown, which highlights the need to expand extrapolation around this question. The Muckleshoot Tribe has collected diet, distribution, and size structure data for sculpin in Lake Washington, but these data are not yet available for review or analysis (Eric Warner, personal communication).

7. A mechanistic model for estimating and ultimately predicting predation losses as a function of sockeye fry abundance, abundance and availability of alternative prey (smelt, sticklebacks, sculpin, etc.), and seasonal environmental conditions (temperature, transparency, river discharge [during fry migration], and lake productivity) needs to be developed and refined via incorporation of the routine monitoring data, directed research, and simulation modeling. Given the complexity of all the processes that contribute to variability in spawning, recruitment, growth, survival, and interactions with other species in the community, a model is the only feasible method of formalizing what is known, assumed, and unknown about this ecosystem. Such a model would explicitly show our state of knowledge and describe the functional link to the important elements and processes in the lake. The model would necessarily evolve with updated information, it would help identify and prioritize information needs, and help guide management by offering predictions about how the system would respond to changing conditions (species abundance, environmental change, different management scenarios, etc.).

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